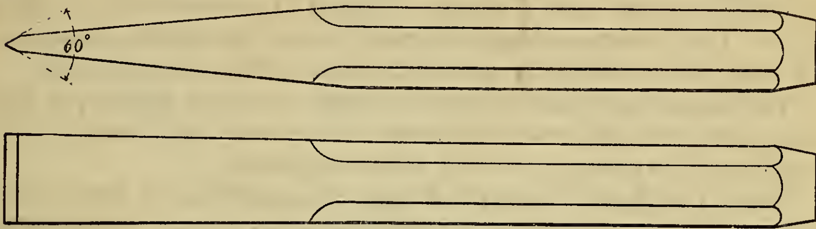
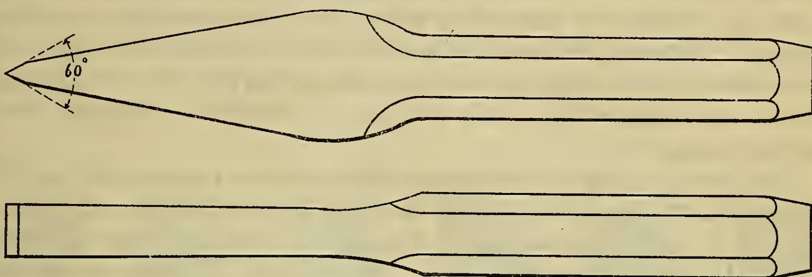
HEBREW TECHNICAL INSTITUTE

SHOPWORK LEAFLETS

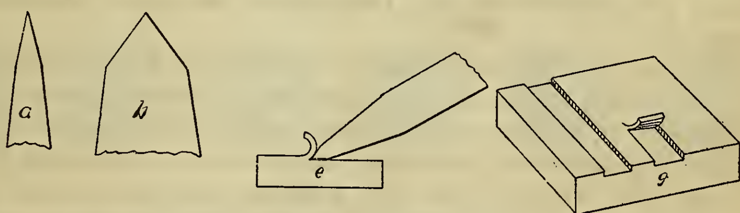
METAL WORK



FLAT CHISEL.



CAPE CHISEL.



CHISELS AND THEIR USE.

The chisel used by the machinist is called a *cold chisel*, as it is used for cutting cold metals and to distinguish it from the *hot* chisel of the blacksmith, used for cutting hot metal. The chisel is an edge tool, and all edge cutting tools must be made of tool steel.

Tool steel may be hardened and tempered, thereby being rendered capable of receiving and retaining a sharp cutting edge. The grade of steel from which cold chisels are made contain 1% of carbon.

Two forms of chisels in general use are the *cape* chisel, and the *flat* chisel.

These are forged from a bar of tool steel, and shaped as shown; the finishing touches being given on an emery wheel. They are then heated to the hardening temperature which is approximately indicated when the work become a cherry color, or perhaps a yellowish incandescence will be more nearly correct. When this point is reached the chisel is plunged into clean cool water when the sudden chill has the effect of refining the grain of the steel and it become extremely hard, so hard in fact, that while it may scratch glass it is too brittle to be used as a tool, for the shock from the hammer blows will easily break it.

The next step is to draw the temper. For this purpose the surface is cleaned, and the chisel slowly reheated to a temperature of about 500° F. This is indicated approximately when the surface becomes a dark straw color, when it is again cooled and is then ready for use.

The tempering process softens or anneals the steel slightly, so that it may withstand the strains to which it is exposed, but does not make it soft enough to prevent retaining the cutting edge.

When the chisel becomes dull from use, care must be taken while sharpening, not to overheat it, and thus draw the temper. It should be pressed lightly on an emery wheel and be kept moving slowly from side to side across the face of the wheel and must frequently be dipped in water. If this is not done the surface will turn blue, indicating that the temper of the cutting edge has been drawn too far, that the edge has become too soft for the work, and that it will have to be again hardened and tempered.

The included angle of the cutting edge should be between 50° and 60°. If ground to the form shown at *a*, the angle is too acute, the edge is too thin, and it will not stand up to the work. At *b*, is shown incorrect grinding in the opposite direction. The angle is too blunt, it will not cut freely, and requires great force to make it cut at all. Remember that all tools must be not only *sharp*, but of the *correct shape* in order to cut well.

To use the chisel, hold it lightly in the left hand at the angle shown at *e*, the hammer blow will cause it to move forward cutting off a chip which curls as shown, while the lower surface of the chisel being nearly parallel with the surface of the work will prevent it from sinking too deep into the metal which is being cut. If the cut is too deep, a slight lowering of the hand will cause the cut to rise, while raising the hand will cause the chisel to cut deeper.

When chipping flat surfaces, as shown at *g*, it is best to begin by making several cuts with a cape chisel. As this chisel is narrow and the edge is slightly wider than the body, little labor is required and the depth and direction of the cut may readily be controlled. The remaining material may then be removed with the flat chisel and if its edge be permitted to rest on the part previously cut, this will prove an efficient aid in obtaining a flat surface.

In the case of the first and second exercise it is necessary to remove only the hard skin of the metal in order that the file may not be injured, therefore care must be taken not to cut too deeply and thus reduce the size of the work below the proper dimensions.

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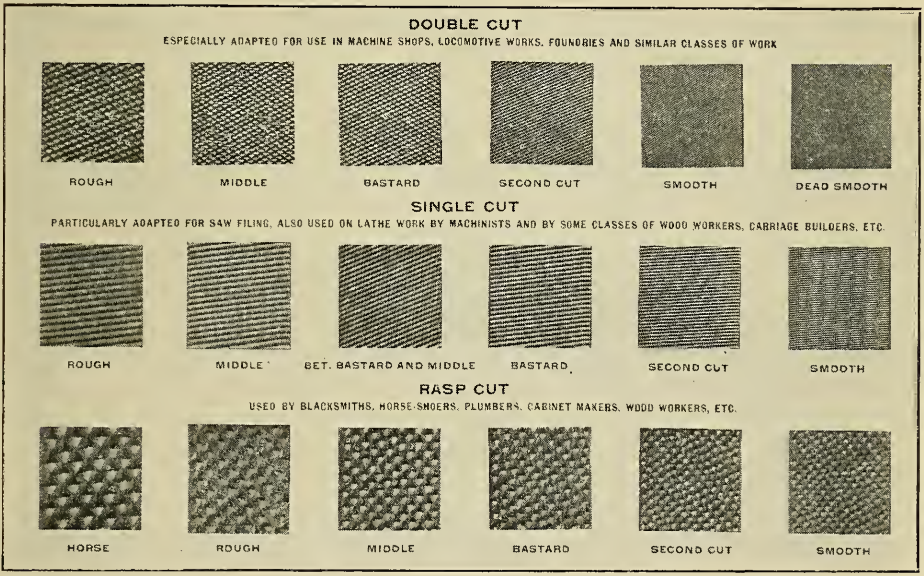
FILES.

Files are made of tool steel, and they cut the material upon which they are used by means of the sharp edges, points, or teeth which are formed on one or more of their surfaces.

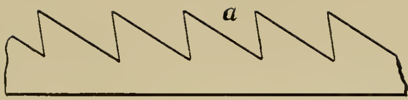
Files are made in a great variety of shapes and sizes, but only a few of these are employed on any particular class of work. They are named according to the shape of the file, and the size and character of the teeth. For the simpler kinds of metal work the teeth used are known according to size, as bastard, second-cut, smooth, and dead smooth; according to shape (cross section), as flat, square, round, half-round, equaling, three-square, and pillar: these again have many variations of shape for special purposes.

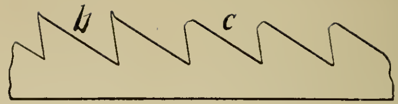


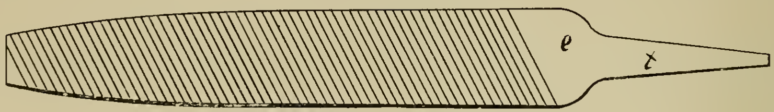
The teeth may be single or double cut. If one or more surfaces have no teeth they are known as safe edge files.

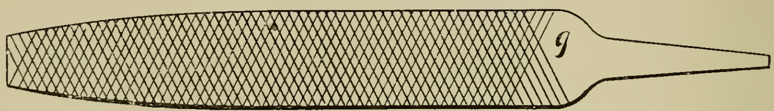
The teeth are generally formed at an angle to the sides of the file, in order that they may cut more easily. Looking down upon them they resemble a number of small chisels or plane irons, while if the file is held level with the eyes they appear like the teeth of a saw, as shown at *a*.

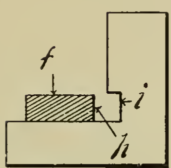
The teeth are cut with a chisel, either by hand or machine, the distance between them being gradually increased from the end to the centre, and gradually decreased from that point to the other end of the file.

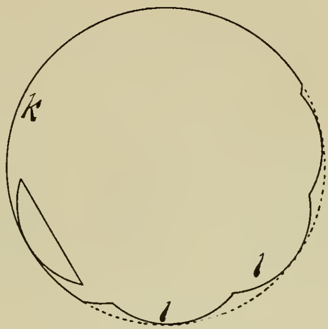


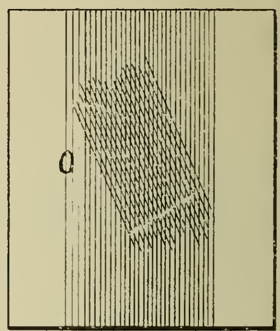












This is called the increment cut, and makes the file cut more smoothly. It is also sometimes done by varying the angle of the teeth. Single-cut files have but one set of teeth as at *e*, while on the the double-cut, another set, not so deep as the first, are cut across them as at *g*. This breaks the continuity of the cutting edges, and forms a number of cutting points.

While the latter will cut more freely than the former and is therefore more generally used for hand filing, the single-cut file will produce smoother results when used on work revolving in the lathe. For this reason they are often called lathe files, or float files. As an aid in filing flat surfaces the file is frequently made thickest in the centre, and slightly curved throughout the length of its broadest side. When held lightly this will tend to make it cut in the centre, and when pressure is exerted while filing, it will spring enough to neutralize this slight curve or belly.

Pressure should be exerted only during the forward motion of the file, and should be removed during the return stroke, also a new file should be carefully used until the feather edges *b* on the extremities of the teeth are worn off. If it is roughly used these points will break off and form a neutral angle *c*, rendering the file useless. It is best to use a new file on brass, and when it becomes too dull for good service on this metal it will still be excellent for use on iron or steel.

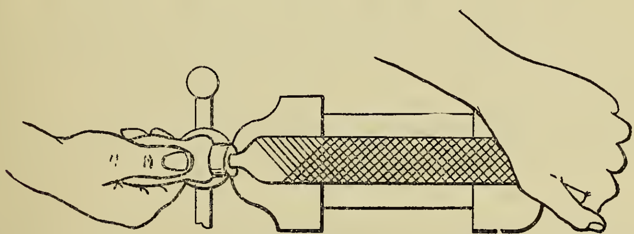
Do not use a file of this description on wood or rubber, for it will soon become useless; neither should it be used on cast iron before the skin of the casting has been chipped off, as the hard skin which contains sand and scale will quickly grind the edge from the file teeth.

When filing a corner, a pillar file *f* with a safe edge *h*, should be used, otherwise the teeth on the edge will cut a recess as at *i*, where it is not wanted. In filing an internal curve *k*, with a half round file, if it is moved straight forward and back, small grooves *ll* will be formed and it is extremely difficult to remove the points between them. Therefore while moving forward and back, the file should also be moved along the circumference of the circle with a sort of diagonal stroke in order to produce a smooth surface.

When filing a flat surface the file should be moved straight ahead in the direction of the greatest length of the work, in order to obtain the greatest amount of bearing surface. When the surface is a narrow one the file should be moved along a line about 45° to the edge of the surface. In finishing work the file is sometimes held at right angles to the length of the surface which is being filed and moved sideways along it. This is called draw filing.

When filing wrought iron or steel, small particles of metal often wedge themselves between the file teeth and make deep scratches in the work. These may be removed with a file card, or brush, or by digging them out with a bit of sheet brass. This trouble may be prevented to some extent by rubbing chalk, or a little oil on the file.
This, however should not be done when filing cast iron, as it will prevent the file from cutting.

When filing a broad surface, as in the case of the first exercise, the tendency is to make the centre slightly higher than the edges. This is difficult to detect when the file is moved always in one direction. If the angle of movement be changed slightly, (not more than 20°), the high spot will be clearly indicated by the cross lines shown at *o*. While this is an aid in producing a flat surface, do not change the angle too much or the result will be worse than before.



The tang of the file *t*, should be firmly placed in a solid handle. (If the handle is split discard it at once). The handle should rest in the palm of the right hand, and be grasped firmly by the fingers, the thumb resting on top of and parallel to the handle, the other end of the file being held with the left hand as shown.

Exert sufficient pressure to make the file bite, and move it slowly forward, being careful to keep it as nearly level as possible, and to guard against the natural tendency to produce a rounded surface, which is done by steadying the arm against the body until sufficient control has been acquired to permit of a free arm movement.

Stand in an easy natural position with the left side of the body nearest to the bench, and with the weight on the left foot. If possible have the work so placed that the surface to be filed is about level with the elbow.

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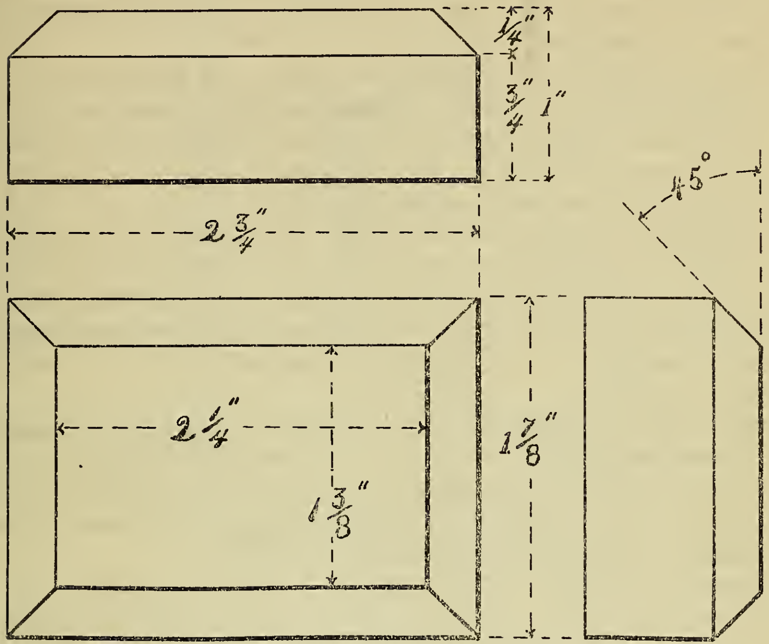
METAL WORK 1918.



CHIPPING AND FILING.

A rectangular cast iron block is supplied, which is required to be chipped and filed to the shape and sizes shown in the above cut.

As the surfaces are hard and contain some sand, it is necessary to remove the outer surface, or skin, with a chisel, for if this is not done the file will quickly be worn out.

Hold the casting firmly in the vise, with the cape chisel chip two parellel cuts along the length of one of the large flat surfaces. Make these cuts about $\frac{3}{8}''$ from each edge and just deep enough to remove the skin; keep them as nearly level as possible and stopping about $\frac{1}{4}''$ from the end, reverse the work and complete the cut from the other direction. This is done in order to prevent the edges breaking off, which is likely to occur if the cut is taken clear across in one direction.

Do likewise on all the surfaces, except that the narrow sides require but one cut.

Next remove the remainder of the skin with the flat chisel, shifting it from side to side, and resting a portion of the chisel edge on the surface already cut, in order to help in producing a surface as nearly flat as possible.

Now with a coarse file, level one of the large surfaces, and test with the edge of a square, in all directions. When it is perfectly flat, stamp it with your initials both for the purpose of identification as your work and as the face side. This side is now known to be correct and must not be altered.

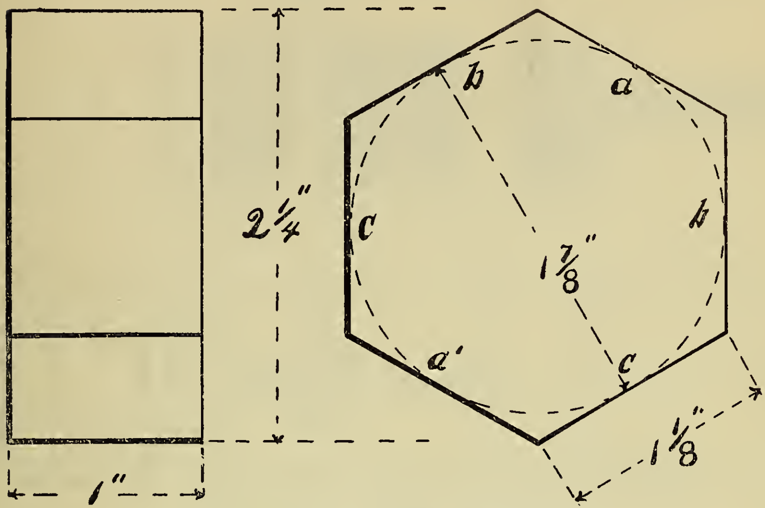
Proceed to file the opposite side in the same manner, and test it not only with the square, but with the callipers, in order to see that it is parallel to the face side.

Next, file one of the long narrow edges, and with the square see that it is flat and square with the face side; call this surface the face edge.

In the same manner file the opposite edge, seeing that it is parallel to the face edge; and then file the two ends. The latter must both be squared from the face edge and the face side.

Now copper plate the narrow surfaces and the side opposite the face side: with the scratch gage, scratch a line $\frac{1}{4}''$ from the edge around the plated surfaces. When these lines are joined by filing away the corners, surfaces at an angle of 45° from the original ones will be formed, as may be seen in the cut. Test these surfaces for truth with the mitre square.

Having produced the correct shape with the coarse file, finish all the surfaces with either a second cut, or a smooth file making the grain run in the direction of the length of each surface, and using a cap of copper or brass over vise jaws, in order to prevent the finished surfaces from being marred when they are held in the vise.



CHIPPING AND FILING.

With the chisels remove the skin from all sides of the casting in the same manner as in the previous exercise, and then file one of the large surfaces, mark it for the face side, file the opposite surface and test both as before.

From the centre of the face side scribe a circle with the dividers, as shown by the dotted lines in the cut.

File the two narrow surfaces *a*, *a'*, square to the faceside, parallel to each other and touching the circle; these will be known as the face edges.

Next file the surfaces *c c*, testing them from the side *a'*, and the surfaces *b b* testing from *a*. Of course all must be square from the face side.

Finish with a smooth file as in the first exercise.

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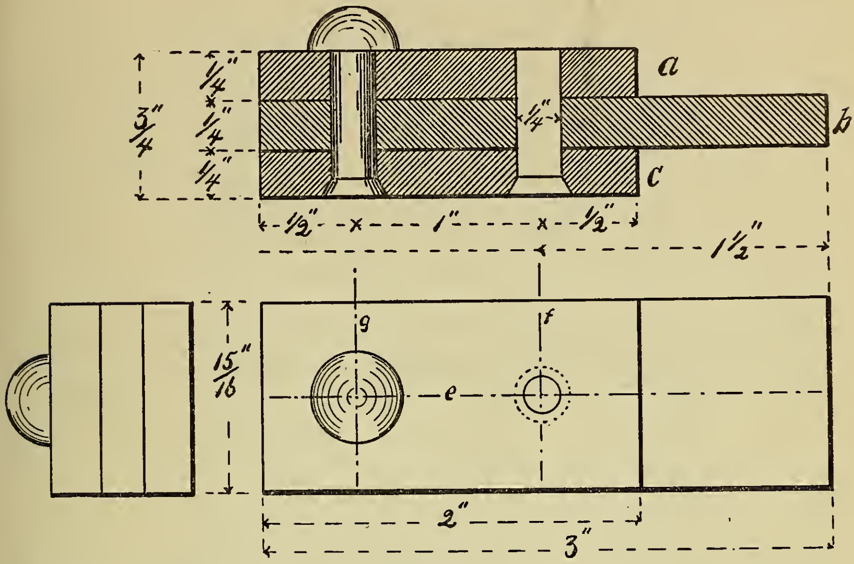

RIVETING.

From a piece of cold-drawn steel $\frac{1}{4}''$x$1''$, cut three pieces of a little longer than the finished length shown.

Square the ends *a, b, c,* and with the scratch gage, draw the line e through the center of each piece, and the line *f* $\frac{1}{2}''$ from the end of *a* and *c,* and $1\frac{1}{2}''$ from *b,* as indicated. Also the line *g* $1''$ from *f* on the piece *a.*

Where these lines cross each other, make a centre-punch mark and drill a $\frac{1}{4}''$ hole through the metal, countersinking the hole in *c,* as shown.

Finish the ends of *a* and *c,* also the sides of *b,* and the top of *a,* as these parts cannot be touched after the work is fastened together.

Put the rivet in the hole on line *f,* and with the head in the riveting cup, rivet the other end by spreading it into the countersunk portion of the hole.

File off any projections, and complete the hole for the other rivet, using the hole in *a,* as a guide, countersink it, insert the rivet and proceed as before.

Next file all sides and ends, except those specified above, until they are square and true, then finish with a smooth file and emery cloth.

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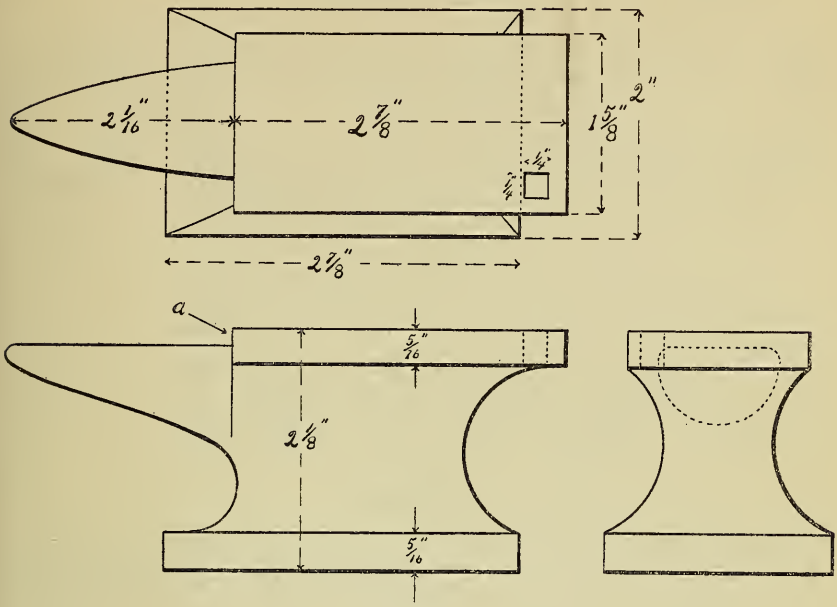

ANVIL.

The material is cast-iron in the form of an anvil.

Place it in the vise on the shaper, and machine the top and bottom to a smooth surface.

Chip and file the narrow edges, with the exception of the top edge next to the nose, which is marked *a*.

File the nose, first with a rough file until all casting marks are removed and then with a second-cut pillar file until the surface is smooth.

Now finish the edge *a*, being careful to use a safe edge file, in order to get the corners nice and square.

Lay out, and drill a $\frac{1}{4}''$ hole, and file it square as shown.

Finish all surfaces except the hollow curved sides, with file and emery paper, and paint the unfinished surfaces with black enamel.

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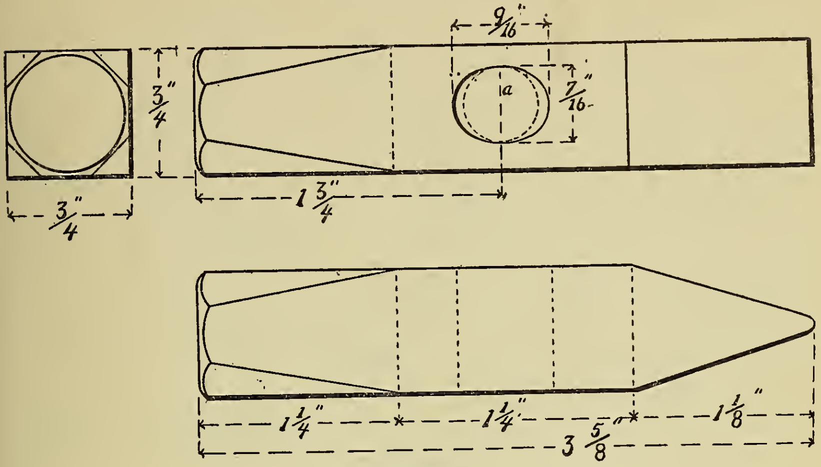

HAMMER.

Cut off a piece of cold-drawn steel $\frac{3}{4}''$ square, and square the ends to the length given in the illustration.

Scribe around it, the lines shown $1\frac{1}{4}''$ from one end, and $1\frac{1}{8}''$ from the other.

File the corners from one of the lines to the face end, until an octagon is formed as shown on the face end.

File from the other line to the peen end, forming the wedged-shaped peen; leave this about $\frac{1}{16}''$ thick, and round it as shown.

Locate the centre of the eye on the line *a*, drill through first with a $\frac{1}{8}''$ drill and then with a $\frac{7}{16}''$ drill, forming the circle shown by the dotted lines, lengthen this with a round file until the oval hole is formed.

Round off the edges of the face as shown, then finish with file and emery paper, to a high polish all over.

Fit the handle to the eye, cut a slot for the wedge, sandpaper, and shellac it; then set it in the eye and drive in the wedge.

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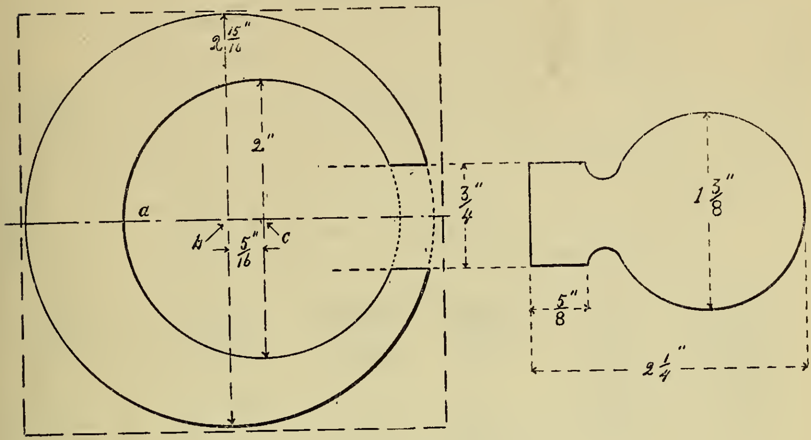

C GAGE.

Material, cold-rolled steel 3″ wide, $\frac{3}{32}$″ thick.

Cut off a piece three inches long, thus forming a square as shown by the dotted lines.

Scribe the centre line *a*, at right angles to the original edge of the material.

On the centre line lay out the centres *b* and *c*, and draw the circles indicated with these points as centres.

Lay out the two lines at the right and parallel to the centre line using the original edge as a guide for the square.

Now drill a row of holes inside the smaller circle; these holes should be about $\frac{1}{8}$″ in diameter, and should just touch each other, but should not touch the circle.

The central part of the metal may now be removed, and the inner circle filed exactly to the line by means of a half round file. Next cut out the metal between the parallel lines and file them, being extremely careful to produce smooth and correct surfaces.

Now shear the waste material off the outside, and file to the larger circle.

Next cut off a piece of the same material in order to make the other part of the gage. File one end carefully to an exact fit between the parallel ends of the first piece, and finish the end to a circle as shown.

Drawfile all the edges to a fine finish, file the flat sides smooth, and finish with emery paper.

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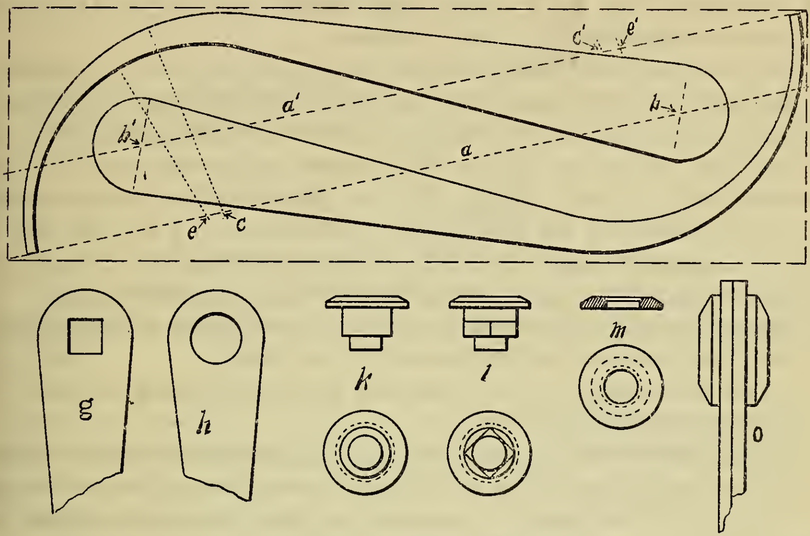

OUTSIDE CALLIPERS.

Procure a piece of cold-rolled steel $\frac{3}{32}''$ thick and $2\frac{3}{4}''$ wide, cut off a piece $5\frac{3}{4}''$ long. This is represented by the large rectangle outlined by broken lines in the illustration.

Scribe the two lines *a*, *a′* running diagonally from one corner to a point $\frac{5}{8}''$ from another as shown.

Locate the centre *b*, on the line *a*, one inch from the edge and draw the circle indicated $\frac{11}{16}''$ in diameter.

On the same line, and at a distance of $3\frac{1}{4}''$ from the point *b*, locate the point *c*, and draw the arc forming the outside curve of the calliper leg with a radius of $1\frac{7}{16}''$.

$\frac{3}{16}''$ farther along, locate the point *e*, and draw the inner curve with a radius of $1\frac{3}{16}''$.

Connect the curved lines by straight ones as shown, and one leg has been outlined.

Proceed in the same manner to locate the centres *b′*, *c′*, *e′*, on the line *a′* and outline the second leg of the callipers.

By means of a row of connecting holes such as were used to cut out the centre of the C gage, separate the legs, and after cutting away as much of the surplus material as possible, drill the centre holes *b*, *b′* with any drill about $\frac{1}{8}''$ in diameter.

Run a pin, or bit of wire of the same size, through the centre holes, clamp the legs with a hand vise, and file to the lines, being careful to file exactly to the lines and not through them.

When this has been done, enlarge one centre hole to $\frac{1}{4}''$ and file it square as shown at *g*.

Next, enlarge the centre hole in the other leg to a diameter equal to the diagonal of the square hole, or about $\frac{3}{8}''$, and then file the sides and finish both legs with emery cloth, finally removing any burrs or very sharp edges around the centre holes.

To make the rivet: take a piece of cold drawn steel rod $\frac{5}{8}''$ in diameter, and turn it to the shape shown at *k*, the large shoulder being made a close fit in the large centre hole at *h*, and of a length exactly equal to the thickness of the two legs; the smaller end being made $\frac{7}{32}''$ in diameter, and $\frac{3}{32}''$ long. When the two shoulders have been turned, and before cutting off the rivet place it in the vise, and with the leg *h* in place to serve as a guide for depth, file the projecting part of the large shoulder square, to fit the square hole in the leg *g*, as shown at *i*. The square part should then be as long as the thickness of one leg, and the round part as long as the thickness of the other.

Replace the work in the lathe and cut it off, shaping the head as shown and making it $\frac{1}{16}''$ thick.

Make the washer *m*, similar to the rivet head, and having a central hole to receive the end of the rivet, slightly chamfered at the outer edge.

Having polished the rivet and washer, place the parts together as shown at *o*, head over the rivet, and drawfile and finish the edges.

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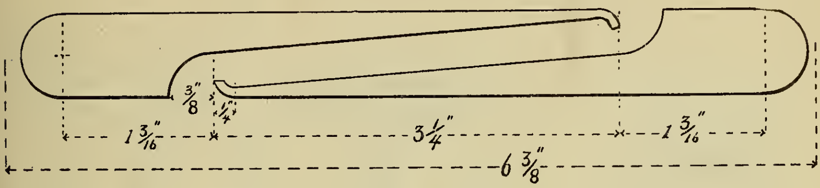

INSIDE CALLIPERS.

Cut off a piece of cold-drawn steel $\frac{3}{32}''$ thick, $6\frac{3}{8}''$ long and $\frac{11}{16}''$ wide.

Make two centre punch marks in the centre of the metal, and $5\frac{5}{8}''$ apart; around these scribe the semi-circles forming the large ends of each leg.

Square two lines across the metal $1\frac{3}{16}''$ from the centres; these will give the length of the legs as shown. With these lines, and the edge of the metal as centres, scribe the circles with $\frac{3}{8}''$ radius, and on the other side of these lines scribe the two small curves forming the ends of the legs, leaving the legs $\frac{3}{32}''$ wide at this point.

Connect the curved lines by straight lines, and then drill the pivot holes with a $\frac{1}{4}''$ drill.

As in the case of the outside callipers, cut the legs apart, file and finish them, and then drill and file the pivot holes.

The pivots or rivets are made in the same manner as those for the outside callipers.

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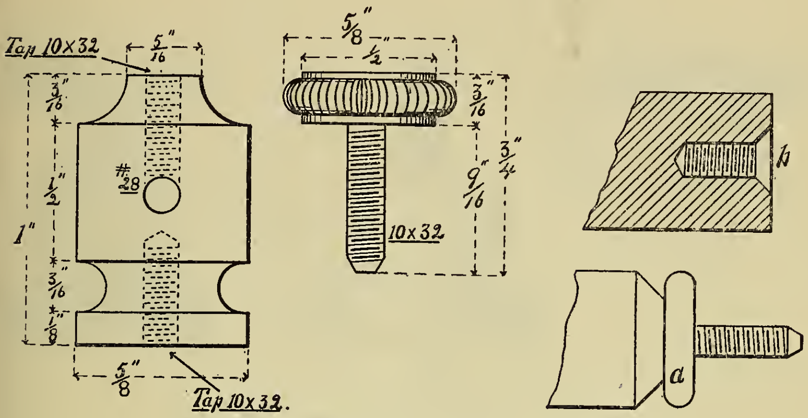

BINDING POST.

For this, the first exercise on the speed lathe, the material required is a piece of $\frac{5}{8}''$ brass rod, $1\frac{7}{8}''$ long.

Hold it in the chuck, and with the lathe running at high speed, turn one end down to the dimensions shown for the thread; then, after chamfering the end of the thread on the screw, turn the head as shown at *a*, to receive the knurling tool. After the head has been knurled, cut off the screw with the hack saw and lay it aside.

Face off one end of the remaining piece of brass, centre it with the tool, and drill to a depth of $\frac{7}{16}''$ with a No. 20 drill. Hold the drill in a hand vise for this purpose, and be careful to keep it straight.

After tapping the hole with a 10x32 tap, chamfer the edge of the hole as shown at *b*, and before removing the work from the chuck, run the screw into the hole just tapped which will serve as a false chuck and hold the work while the head of the screw is being finished. Face the head smooth, and make the two small shoulders shown, one on either side of the knurled portion.

Now remove the work from the chuck of the lathe, and place it on a false chuck; face off the end, drill, and tap it as before to a depth of $\frac{9}{16}''$, and then turn the grooves shown. Bear in mind that a groove should be narrow in proportion to its depth in order to look well.

Then the central hole for the wire must be drilled with a No. 28 drill, and the work is ready to be polished with emery cloth.

Care must be taken during each step to keep the work true in the chuck, or it will be spoiled

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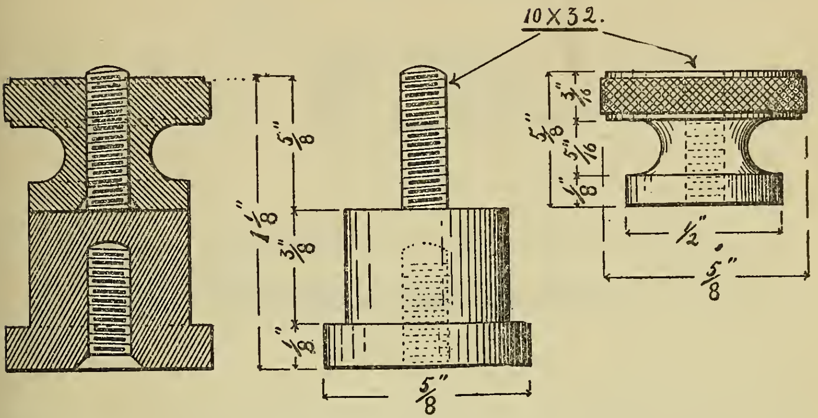


BINDING POST.

This exercise differs in shape from the previous one, but is of nearly the same size, and requires the use of similar tools in its construction.

The material is a piece of brass rod $\frac{5}{8}''$ in diameter and $1\frac{7}{8}''$ long. Grip it in the chuck on the speed lathe, being careful to see that it runs true, and face off one end with the side tool: centre it for the drill, then drill with a No. 20 drill for a distance of $\frac{5}{8}''$, and tap the hole with a 10x32 tap as shown.

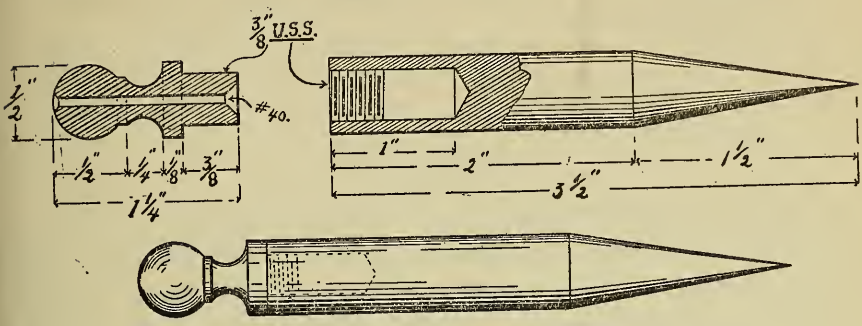
Now turn the groove for the neck, and knurl the part which is to form the head of the post. With the hack saw this portion may now be cut off and laid aside for the present.

Face off, drill, and tap the remaining piece of metal which will form the base of the post, and place it on a false chuck. This brings it in a convenient position for completing the work, which is done by turning it to the size shown and cutting the thread of the screw which projects from the base.

Turn the base to the shape indicated, and make the smaller part $\frac{1}{2}''$ in diameter: place the top of the post in position, and face the knurled end. This finishes the post with the exception of polishing; which is done with a piece of fine emery cloth.

SHOPWORK LEAFLETS

METAL WORK



PLUMB BOB.

Cut off a piece of cold-rolled steel $3\frac{5}{8}''$ long, and $\frac{1}{2}''$ in diameter. Place it in the speed lathe chuck, and, running the lathe at slow speed, face off one end, and centre it for the drill.

With a $\frac{21}{64}''$ drill, make a hole one inch deep (or if the bob is to be weighted with mercury, then drill the hole two inches deep). Tap this with a $\frac{3}{8}''$ tap, and chamfer the edges of the hole.

Reverse the work, and turn the other end to a point as shown for a distance of $1\frac{1}{2}''$.

Next place a rod of brass of any convenient length and $\frac{1}{2}''$ in diameter in the chuck, turn one end to $\frac{3}{8}''$ in diameter and $\frac{3}{8}''$ long, being careful to form a true and square shoulder. Cut a thread on this part with a $\frac{3}{8}''$ die, and saw from the rod a piece $\frac{7}{8}''$ longer than the threaded portion.

Screw it into the hole previously threaded in the steel piece, and using this as a false chuck, turn the brass to the shape shown.

Drill a hole clear through the length of the brass with a No. 40 drill, and chamfer the edge of the hole so that it will not cut the string.

Polish the steel by graining it lengthwise with emery cloth, and polish the brass and half an inch of the steel next to it while the lathe is running.

SHOPWORK LEAFLETS

METAL WORK

LATHE TOOLS.

Lathe tools may be made of carbon steel, in which case they are forged to the required shape and hardened and tempered in the usual manner. One of the many varieties of high speed steel may also be used, in which case a piece cut from a bar of the proper cross section serves as the cutter, and is clamped in a conveniently shaped holder when in use.

The latter form is convenient for general use as the material may be purchased already hardened throughout the bar; while the variously formed holders support the cutter in the best position for effective service. It may also be employed for heavier and more rapid cuts than a tool made of carbon steel, and may be ground with little danger of drawing the temper, which is not the case with the regular carbon tool steel. It does not, however, take such a fine edge nor can it produce as fine a tool finish as carbon steel.

Lathe tools are made in a large variety of shapes for the different kinds of work and materials upon which they are to be used. It is therefore beyond the limits of this paper to illustrate more than a few of the fundamental principles embodied in their construction.

In a general way it may be stated, that tools must be properly shaped for the work they are to do, that they *must be kept sharp* and when they become dull it is not sufficient to sharpen merely the dull portion, but the grinding must be done in such a manner that *the original shape will be preserved.* The cutting edge of the tool must be properly placed against the work, irrespective of the position of the body of the tool, and it should be so ground that all parts slant away from the cutting edge in order to cut clean and readily clear itself of chips. In turning metal the cutting edge should, theoretically, touch the work at a point horizontally opposite the centre, but this position is variable according to the size and character of the material, the speed, and the character of the tool. For general conditions, when turning externally,

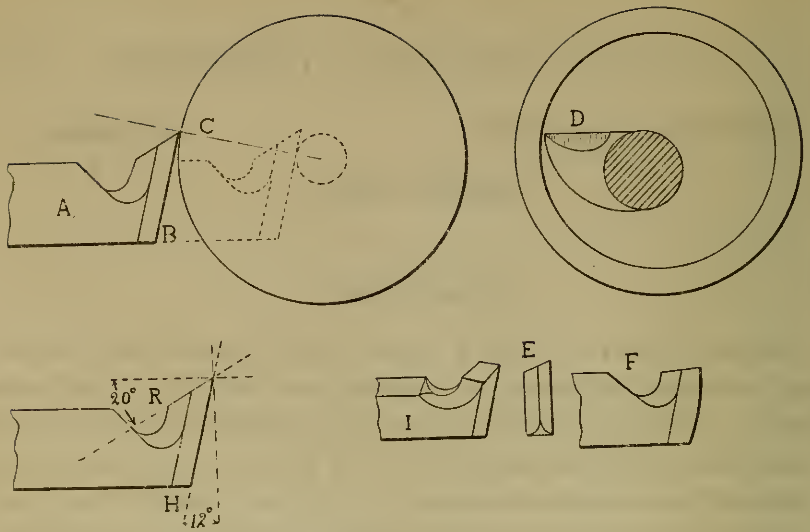


Fig. 1.

a favorable position is shown at A Fig. 1, where the point is so placed that the edge B is tangent to the circumference of the work; as the work decreases in diameter the point should be lowered along the line C. If this is not done the point would leave the surface as indicated by the dotted lines.

For internal cutting, the best results are obtained with the edge above the centre, the edge being ground with a slant as shown at D.

In general, and particularly in the case of tools for roughing cuts, the front of the tool should incline toward the heel H for clearance, and the top should have sufficient top rake R to permit the material to cut easily and permit the chips to slide freely off the top of the tool, while at the the same time these angles must not be so sharp that the tool will have a tendency to dig into the work, or that the cutting edge will break due to weakening the support below it. While the correct amount of inclination at these points is still a debatable question, the angles shown are generally serviceable. If the tool is to move toward the left a small amount of side rake E is advisable. At F is shown a tool which has been ground without regard to the preservation of the shape, and a little thought will prove that the loss of top rake will require increased power to make the tool cut at all as the chips are forced off at an abrupt angle, while the loss of front clearance will prevent the point from reaching the work unless the tool is set at an abnormal angle in which case the trouble due to the deficient top rake is enormously accentuated.

The diamond point tool, I, is used for roughing and for heavy cutting. It is usually ground as a right side tool and has both top and side rake as shown at E.

In the case of parting and thread cutting tools there should be little if any top rake, and no side rake. Tools for brass may be fairly sharp pointed without top rake; those for steel slightly rounded at the point while those for cast iron may be rather well rounded and present a broader cutting edge to the work.

The foregoing instructions regarding the shape and position of lathe tools are subject to slight variations due to the character and size of the work, the material being machined, and the convenience of the operator.

For facing the ends of small pieces, and for producing smooth cylindrical surfaces, the side tool A Fig. 2 is convenient. This tool may be forged of carbon steel to the shape shown, and either right or left hand as required. The one illustrated is a right side tool (it cuts the right hand end of the work) and cuts only when moving from right to left. The pointed end of this tool permits it to cut clear to the lathe centre when used for facing, and if ground with a small flat at the end and used on a light cut with a cooling fluid it will produce a smooth polished surface.

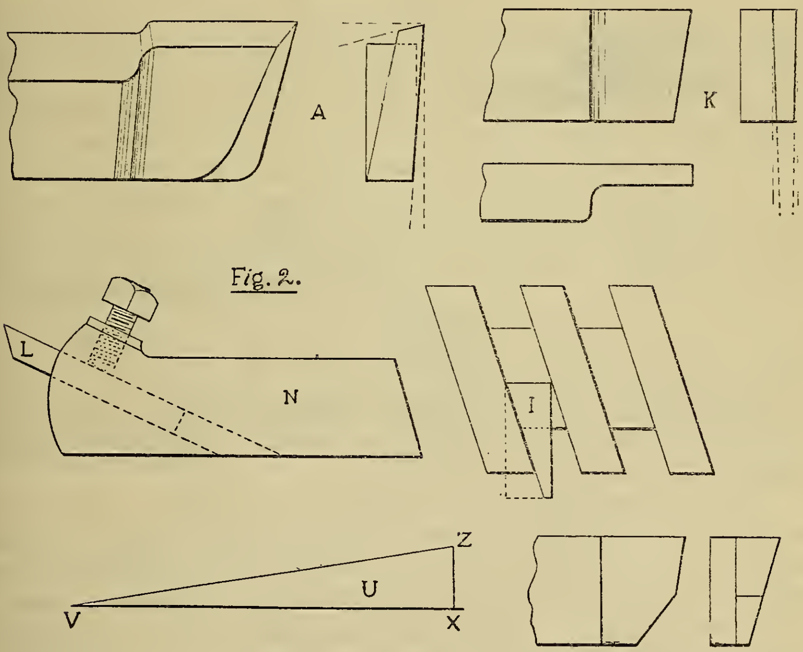


Fig. 2.

The parting tool K, Fig 2, is used for cutting off, and for making grooves. The front of the tool is square with the centre line and the sides may be very slightly narrower at the back than at the front in order to prevent binding in a deep cut. Both sides are given a slight clearance as shown by the dotted lines in the end view. This tool should only be used for cutting straight toward the centre of the work, and it is sharpened by grinding the front or cutting edge.

The tools previously mentioned are usually made of carbon steel but to meet the requirements of modern machine work as to high speeds and heavy cuts, tools made of a specially alloyed steel are now commonly used. On account of the cost of material and for convenience of operation this steel is usually furnished in bars of suitable size and shape; these bars are cut in short lengths and the cutters thus formed are held in properly shaped holders.

In Fig. 2, the cutter L is of this high speed steel and N is the holder; it will be noted that the cutter is held at such an angle that the top rake is automatically produced. These holders are made straight, and right or left, in order that the cutter may be held in any desired position.

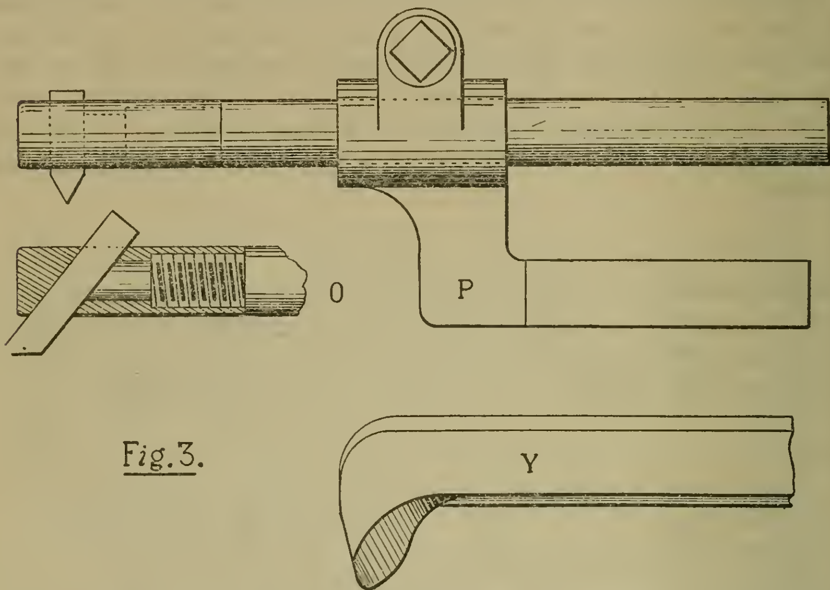


Fig. 3.

At P, Fig. 3, is shown a holder suitable for either a boring or a threading tool; the latter is shown in position, but by substituting the head O the boring tool may be used.

Thread cutting tools require little or no top rake. In the case of the angle side thread tools, such as are used for U. S. S. threads, the tendency of the tool is to dig into the work, and any considerable top rake will make this tendency more pronounced. On this account Square and Acme threads are frequently roughed out with a smaller tool and finished with one of the correct size, and in cutting Vee and U. S. S. threads the tool may be fed in at an angle corresponding to the side of the thread; this relieves the pressure on one side and to some extent counteracts the tendency of these tools to dig into the work.

Threading tools for use in holders are correctly formed throughout their depth and should be ground only on top when being sharpened.

As a thread advances along a spiral line, the front center line of the tool should coincide with the center line of the spiral; this angle varies with the pitch of the thread and the diameter of the work. The necessity for thus placing the tool is particularly noticeable in the case of the square thread tool I. Fig. 2, where, if the tool should be ground like a parting tool, which it closely resembles, the dotted portion would prevent it from entering the cut. Such tools require considerable clearance on one side except when made of round stock in which case they may be so placed in the holder as to conform to the required angle.

The amount of clearance may be found by reference to U, Fig. 2. Lay off on the line V X a distance equal to the circumference at the bottom of the thread, make the line X Z equal to the pitch distance and draw the line V Z; this line indicates the angle to which the tool must be ground.

Always use a gage when setting the thread tool, and see that the top center line of the tool is at right angles to the center line of the lathe; if possible always cut taper threads on a lathe fitted with a taper attachment, for if it is necessary to cut them with an offset center the pitch will be inaccurate.

When cutting threads the tool should be backed out of the cut on returning the carriage to the starting position, because on all lathes there is a certain amount of lost motion due to wear, or improperly fitting gears, and the tool will not return along the path taken when in the forward motion. For the same reason when resetting a threading tool see that all other parts are in the forward motion, which may be done by pulling the belt by hand, before adjusting the tool; or the tool may be set, the idler gear dropped and the lathe turned by hand until the tool is in the proper position when the idler may be re-engaged. If the lathe has a compound rest, set it at an angle and the tool may readily be aujusted by this means.

Forged boring tools may be formed as at Y, Fig. 3, or the holder previously described may be used, the latter is preferable as the distance from the cutting point to the point of support may be adjusted in order to avoid too much spring and the position of the cutting edge may readily be changed.

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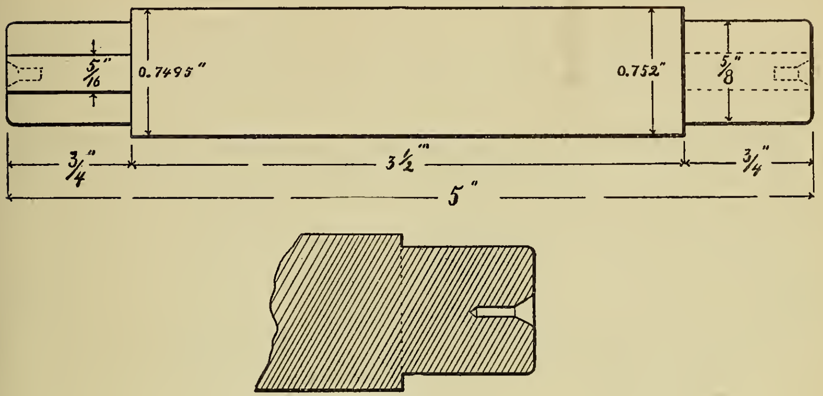
SHOPWORK LEAFLETS

METAL WORK



MANDREL.

Cut off a piece of tool steel $\frac{7}{8}''$ in diameter, 5 $\frac{1}{16}''$ long.

Find the centre of the ends, centre punch them and drill with a No. 34 drill to a depth of half an inch, then countersink to a diameter of $\frac{1}{4}''$. (This holds good whenever a piece of work is to be prepared for turning on the centres of the lathe).

Face the ends square with a sharp nose side tool, and bring the work to the length required.

Turn the work throughout its length with the roughing tool to a diameter $\frac{1}{64}''$ larger than the finished size. Turn the ends as indicated, allowing the $\frac{1}{64}''$ oversize for finishing. Remember that work should never be turned to the finished size at first, but all parts when roughed out should be left larger by an amount sufficient to allow for final finishing to the correct size: this amount varies with the character of the work.

Chamfer, or round the corners as indicated in the part drawn in section, then file the flat spots on each end as shown.

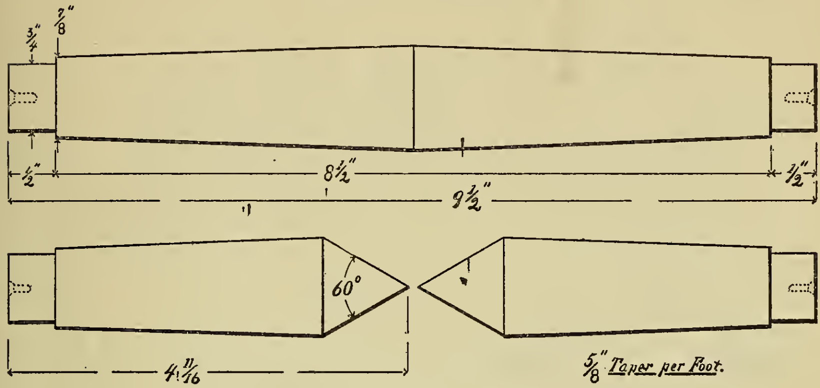
Stamp one of the flats with a number indicating the finished size of the mandrel, and harden it.

After hardening, lap out the centres in order to remove all scale, and grind to size. The mandrel should taper an amount as indicated by the figures, and the larger end should be the one upon which the size is stamped.

It is always essential that the lathe centres be sharp and run true. The work should be free to revolve easily, but have no play in the direction of its length DO NOT FAIL TO OIL THE TAILSTOCK CENTRE when work is being turned in this manner.

SHOPWORK LEAFLETS

METAL WORK



LATHE CENTRES.

Cut off a piece of cold-rolled steel $1\frac{1}{8}''$ in diameter, and $9\frac{9}{16}''$ long, centre it, and drill it as in the previous exercise, then square the ends to the required length.

If the lathe has a taper attachment, set it to a taper of $\frac{5}{8}''$ per foot: if not, then set the tail stock over as far as necessary to produce this result (see leaflet on taper turning). This will be in this case 0.247″ or practically $\frac{1}{4}''$.

With the roughing tool, turn first one end, and then the other until the small ends are $\frac{57}{64}''$ in diameter. Then reduce the diameter of the ends for a distance of half an inch as shown.

Place the work in the universal grinder (oil both centres), and setting the table to a taper of $\frac{5}{8}''$ per foot, grind until the ends are $\frac{7}{8}''$ diameter at the shoulders.

Cut the work in two at the centre, or at the thickest part, and place one of the pieces in the centre hole of the headstock. Set the compound rest at an angle of 30° from the centre line of the lathe and running at high speed turn to a point.

Finish with a lathe file, and proceed in the same manner with the other piece.

The tail-stock centre, being subject to wear should be made of tool steel, and hardened and tempered, the headstock centre may be left soft.

SHOPWORK LEAFLETS

METAL WORK

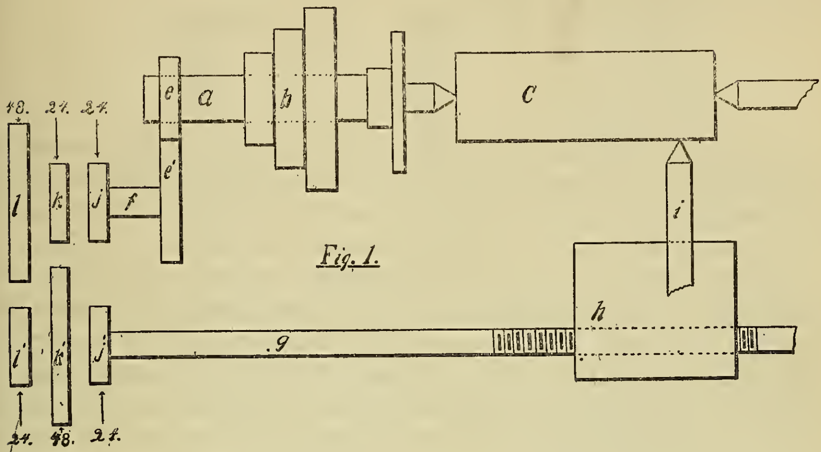


Fig. 1.

THE ENGINE LATHE.

Consider the lathe stripped of all details, and we have the essential factors shown in the diagram Fig. 1; where the spindle *a*, actuated by a belt running on the cone pulley *b*, turns the work *c*, placed on the centres and held by a dog, which is not shown. Also through the gears *e*, *e'* the spindle turns the small shaft *f*, which is known as the stud.

Along the lathe bed, extends the lead screw *g*, which moves the carriage *h*, and the tool *i*.

Let us assume for the purposes of the explanation that the lead screw in this case, has six threads per inch, and that the speeds of the spindle and stud are equal.

If therefore, a gear *j*, be placed on the stud, a gear *j'*, be placed on the screw, and both gears have the same number of teeth, it is evident that if the gears mesh together, when the spindle is revolved once, the stud gears *j*, *j'*, and the screw *g*, will each make one revolution and the tool and carriage (the latter being clamped to *g*, by a split nut) will advance $\frac{1}{6}''$, thus cutting a thread of six to the inch on the work.

If these gears be removed, and the 24 tooth gear *k*, be placed on the stud and the 48 tooth gear *k'* on the screw, then, when the spindle, stud, and gear *k* turn once, the gear *k'* and screw *g*, will make only a half turn, and the carriage will advance but half of $\frac{1}{6}''$ or $\frac{1}{12}''$, thus cutting twelve threads per inch.

Again, if we reverse these conditions, and place 48 tooth gear *l*, on the stud, and the 24 tooth gear *l'* on the screw; then when the spindle and stud turns once, the lead screw will make two turns, and the carriage will advance $\frac{2}{6}''$ or $\frac{1}{3}''$; thus cutting at the rate of three threads per inch.

Bearing the foregoing in mind, and assuming that a thread is to be cut on the lathe, the first step is to look for the plate usually fastened to the lathe upon which is indicated the gears employed, and their location when cutting the thread required. Upon this plate three columns of figures will be found, as follows:

Cut.	Stud.	Screw.
6	24	24
12	24	48
18	24	72

Under the word cut, in the first column is indicated the number of threads per inch to be cut, and on the same line, but in the other columns are shown the number of teeth in the gears to be used, while the word at the head of each column, indicates where the gear is to be placed.

However, if we wish to cut three threads per inch, there is nothing in this table to indicate the gears required. Now bear in mind what has previously been said, and on examining the table it will be found that only one thread (six per inch in this case) is cut by even gears; that is, gears on the stud and screw having the same number of teeth. Also note, that to cut twelve, or eighteen threads, gears are required having the same ratio to each other, as the thread cut by even gears, has to the thread to be cut. For example, gears with 24 and 72 teeth, a ratio of 1 to 3, are used to cut eighteen threads, and the ratio of 6 to 18, (the thread cut by even gears, and the thread to be cut), is also 1 to 3. Therefore as the ratio of 6 to 3, is as two is to one, then gears 48 and 24 teeth, or any others having the same ratio will be used to cut three threads per inch on this lathe.

Rule. *To cut a thread not given on the table.* Multiply the thread cut by even gears, by any number which gives a gear you have with the lathe, and put this gear on the stud.

Multiply the thread to the cut, by the same number, and put the resulting gear on the screw.

If there is no table on the lathe the selection of the gears will prove a simple matter, if the thread cut by even gears is known. In Fig. 1, the stud *f*, makes one turn when the spindle makes one turn; and the resulting thread when even gears are used is the same as that on the lead screw; should the spindle *a*, make two turns to one turn of the stud, then the resulting thread would be twelve per inch, therefore;

To find the thread cut by even gears: Multiply the threads per inch on the lead screw, by the number of turns the spindle makes to one turn of the stud.

Example:—What gears are required to cut 20 threads per inch, with a lathe having a lead screw of 8 threads per inch, the spindle making two revolutions to one of the stud?

8 x 2 = 16 = thread cut by even gears.
16 x 3 = 48 = gear on stud.
20 x 3 = 60 = gear on screw.

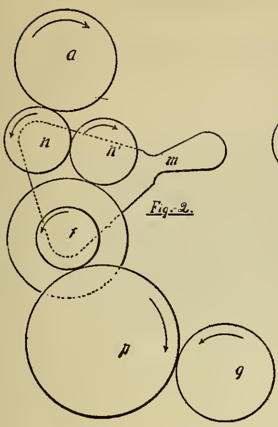


Fig. 2.

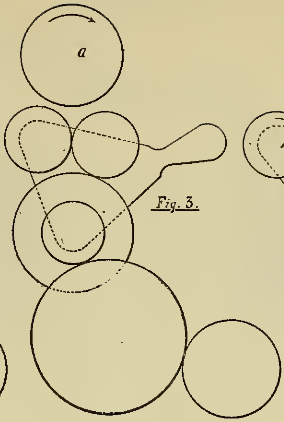


Fig. 3.

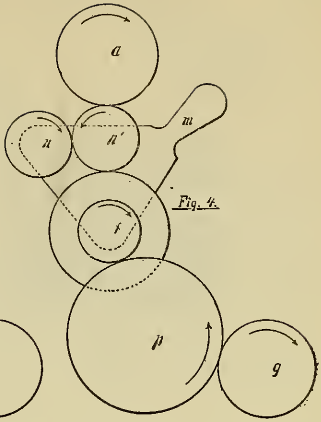


Fig. 4.

The centre distance of the stud, and lead screw being permanently fixed, it is self evident that the gears used would not mesh except in rare instances, for this reason the gear *p*, Fig. 2, is provided: this is known as the idler, and its position may be shifted to enable it to connect the gears *f* and *g* on the stud and screw. As it simply transmits motion, tooth for tooth, and has no effect on the speed of the lead screw, it may be of any convenient diameter.

While the previous statements relate simply to the rate at which the tool advances while cutting threads of any number, or shape, yet in cutting right or left hand threads, the direction of movement of the tool must be reversed while that of the work continues as before. The top moving toward the operator.

Referring to Fig. 2, which is an end view of Fig. 1, two small gears *n*, *n′* will be seen mounted on a plate controlled by the handle *m*, and connecting the spindle *a*, with the stud *f*. With these gears in the position shown, and the spindle revolving in the normal direction, the direction of movement of each gear is indicated by the arrows, and *g*, is seen to be moving in the direction opposite to *a*. With the handle shifted to the position in Fig. 4, the gear *n*, is not in use, and the direction of rotation of *g*, is reversed. While in Fig. 3, with the handle in the central position the entire train of gears is disconnected and there is no movement of the lead screw.

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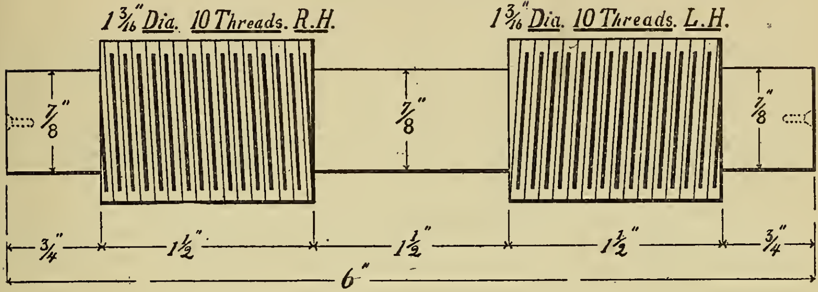
SHOPWORK LEAFLETS

METAL WORK



THREADS.

Cut off a piece of cold-rolled shafting of the required size, prepare it for the lathe in the same manner as for the previous exercise, and turn it to the length and largest diameter shown. Do not forget to allow for finishing.

Turn to the rough diameter and length on each end, then with the parting tool rough out the recess in the centre.

Next with the lathe on slow speed, and with a square-nosed side tool, lubricated with savon oil, soap water or a similar mixture, take a light cut with a slow feed, and finish all over to the exact size, making the measurements with a micrometer.

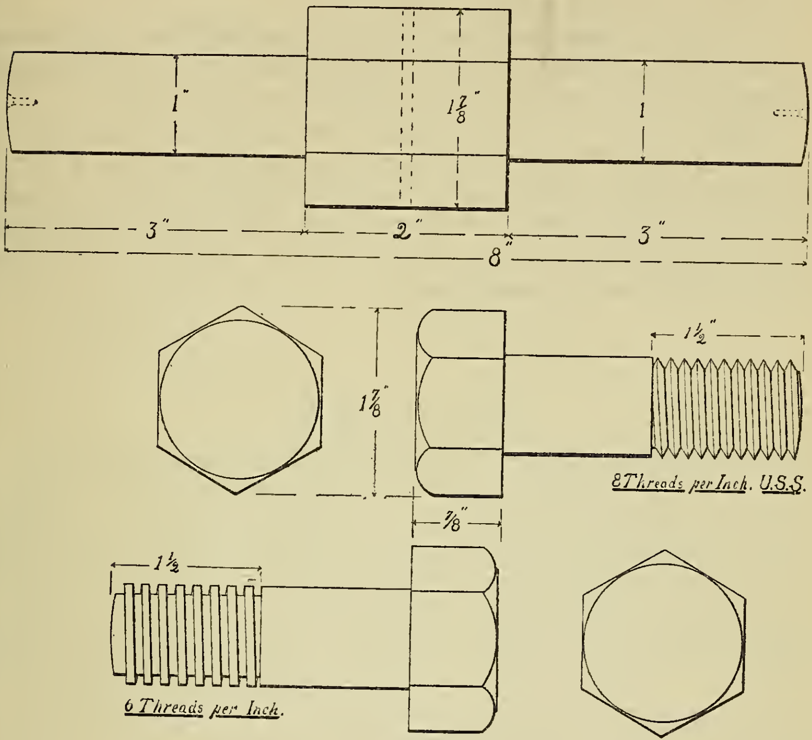
Set the gears for cutting ten threads per inch, and cut a right hand U. S. S. thread on one of the larger diameters. (See leaflet on thread cutting). Then reverse the work, and cut a left hand thread on the other large diameter.

Cut the threads as smooth as possible, and finish by bevelling the edges of the large diameters in order to remove any burrs which may have formed.

Note, that whenever it is necessary to hold work by a chuck or dog, gripping a finished surface, a piece of copper or brass should be placed between the dog screw or the chuck jaws, and the work in order to prevent injury to the surface.

SHOPWORK LEAFLETS

METAL WORK



BOLTS.

Cut off a piece of $1\frac{15}{16}''$ shafting long enough for the work; prepare it in the usual manner, face the ends and rough it off for the sizes shown in the upper figure.

Place it in the milling machine, and with a surface mill cut the six flats forming the hexagons, which will later be the bolt heads.

Replace it in the lathe, and with the square nosed tool finish the 1″ diameter parts in the same manner as the last exercise.

Grind a square thread tool to a width of 0.0833″, (the width of the groove for the thread indicated and with it, cut a groove 0.087″ deep on one of the bolts, $1\frac{1}{2}''$ from the end. This will serve both as a gage for depth and as a convenient place to end the thread neatly.

Set the gears and cut the thread in the usual manner, taking care to keep the surface of the metal smooth and not to go deeper than 0.087″ which equals the working depth plus the clearance, of a square thread having six threads per inch.

Reverse the work; being careful to place a piece of copper or brass under the dog screw, in order that the thread may not be injured.

Proceed to cut an eight pitch U. S. S. thread on the other end. After the first cut has been taken for a distance of $1\frac{1}{2}''$, a small hole may be drilled at the end of the cut so that the thread may finish at this point, or, as in the previous case, a groove may be turned to a depth of $0.081''$, and this will serve for a guide as before.

After both threads have been cut and the ends of the bolts and threads finished off, the parting tool may be used to cut them apart at the point indicated by the broken lines in the centre of the upper figure.

A piece of brass tube, split along its length, is now placed over the body of one of the bolts to protect the finished surface, it is then gripped in a chuck while the top of the head is faced and bevelled as shown in the lower figures. After both bolts have been treated in this way the flats are, if necessary, smoothed in the direction of their length with a pillar file and an emery cloth.

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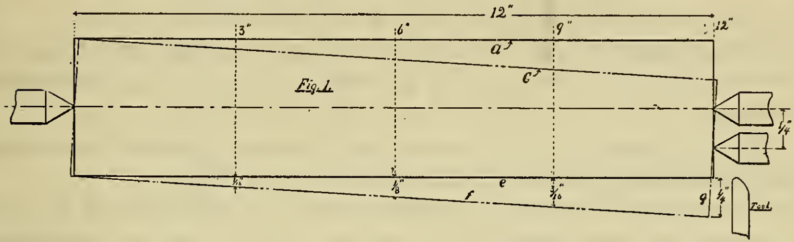
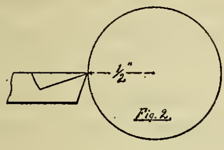
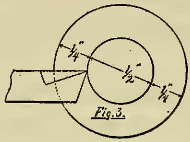
SHOPWORK LEAFLETS

METAL WORK







TAPER TURNING.

The amount of taper is based on the variation in diameter per foot of length. Therefore, if a piece of work one foot long, is two inches in diameter at one end, and one inch in diameter at the other, it is said to have a taper of one inch per foot. Also a piece six inches long, measuring two inches at one end, and one and one half inches at the other; or a piece two feet long, the ends being respectively three inches, and one inch, in diameter will taper at the same rate, and will also be said to have a taper of one inch per foot.

If the lathe is in good condition, and the centres in line, a piece of metal 12″ long placed between the centres will be turned to a true cylinder 1″ in diameter if the tool is placed $\frac{1}{2}''$ from the centre line as shown in Fig. 2, and indicated by rectangle *a*, in Fig. 1.

With the tool in the same position; if the tail stock center be moved toward the operator a distance of $\frac{1}{4}''$, Fig. 1, the work will occupy the position shown by the rectangle *c*, and the tool will make a cut $\frac{1}{4}''$ deep Fig. 3.

A complete revolution of the work will therefore cause its diameter to be reduced $\frac{1}{2}''$ at this point, this amount becoming regularly less as the tool moves to the left, until on reaching the other end of the work it becomes zero, and the original diameter remains.

It will be noted: That a taper of $\frac{1}{2}''$ per foot has been produced in this case.

That, the centre was moved one half of the amount of taper per foot produced.

That the triangle *e, f, g,* represen ng the material removed on each side, becomes narrower in exact ratio to its length. That, were the work 6″ or 9″ long, then a movement of the center of $\frac{1}{8}''$ or $\frac{3}{16}''$ would have produced the same rate of taper.

Therefore we have the rule;

To turn a taper between centres: For work one foot long, move centre over, one half of the amount of taper per foot required.

For work more or less than one foot long, the centre will be moved an amount more or less than the distance required for one foot, in the same ratio as the length of the work is to the length of one foot.

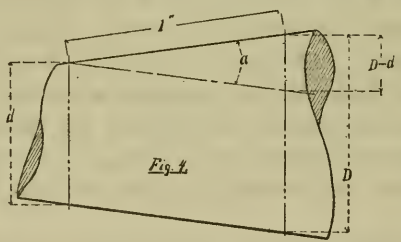
If the centre is moved toward the operator, the right hand end will be the smallest, if in the opposite direction, the right hand end will be the largest.

The tool must cut on the centre line; if above or below, the surface of the work will be convex or concave.

If a taper attachment is provided for the lathe, this should be used; the centres may then remain in the central position, and the attachment set to any required angle within its range without regard to the length of the work.

In order to determine the amount of taper, if a gage is not at hand, measure the diameters at two points one inch apart, their difference multiplied by twelve will be the taper per foot.

For angles beyond the range of the centres, and taper attachment, and for internal work, many lathes are supplied with a compound rest. This is graduated in degrees and may be set at any angle desired. However it must be borne in mind that this amount is but half of the included angle in any case. For example, lathe centres have points turned to sixty degrees, therefore the tool is set at an angle of thirty degrees from the centre line, and as the work revolves while being machined, this line of thirty degrees will sweep around the centre, producing the required angle when measured across the diameter.



The angle may be found in degrees by the following formula:

$$\frac{D - d}{0.0174} = a.$$

where D = Large diameter in inches;

d = Small diameter in inches;

a = Included diameter in degrees;

0.0174 = The chord of an arc subtending an angle of one degree, having a radius of one inch.

After obtaining the included angle by this formula, the measurements being obtained as shown in Fig. 4. set the compound rest to one-half the angle found, for the reasons previously mentioned.

SHOPWORK LEAFLETS

METAL WORK

SPUR GEAR CALCULATIONS.

A wheel having teeth on one or more of its surfaces is called a *gear wheel.*

When several gears are employed to transmit motion they are called a *train of gears.*

A gear with teeth upon its circumference or face, the teeth extending acrosss the face in a direction parallel to the axis of the gear, is called a *spur gear.*

The distance between the centres of two shafts supporting gears which run together is called the *pitch distance, a,* Fig 1.

When the teeth of one gear engage the teeth of another gear they are said to be in mesh.

Gears will run together no matter how great a difference there is in the number of teeth, but, the teeth on both gears must be of the same size and of correct shape.

The central point around which a gear revolves is called the *pitch centre.* If circles are drawn around the pitch centres of such size that they just touch each other, *p, p,* Fig. 1, they are called the *pitch circles.*

The diameter of such a circle is called the *pitch diameter, p,* Fig. 2. The ratio of the diameters of the pitch circles is also the ratio of their relative velocities.

If material be added forming the projections *a, a,* Fig. 2, the corresponding depressions *a,′ a′* must be cut in the mating gear to permit the wheels to revolve.

If similar projections and depressions are formed so that they connect with each other as at *t,* Fig. 2, it will be noted that a complete tooth has been produced, that one half of the tooth projects beyond the pitch circle, and one half is within the circle; also that the whole diameter *b,* of the complete gear measured from the extremities of the teeth is equal to the pitch diameter plus a distance equal to the height of one tooth.

The pitch circle does not appear in the completed gear, but it is important as a basis of calculation. Also a gear whose pitch diameter is 5″ is called a 5″ gear, although the diameter across the extremities of the teeth will be greater than this amount. The circle touching the bottom of the teeth is called the base circle or dedendum.

The circle touching the outer extremities of the teeth, is called the addendum, and its diameter, the whole or *blank diameter.* A gear of small diameter is called a *pinion.* A gear formed of teeth cut on a straight bar forming a part of a gear of infinite diameter is called a *rack.*

The distance between the centres of two teeth, measured along the pitch circle, and at right angles to their length, is called the *circular pitch.*

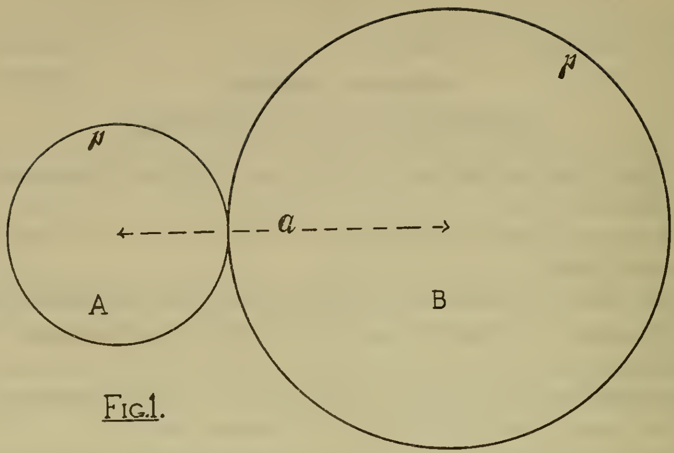


FIG. 1.

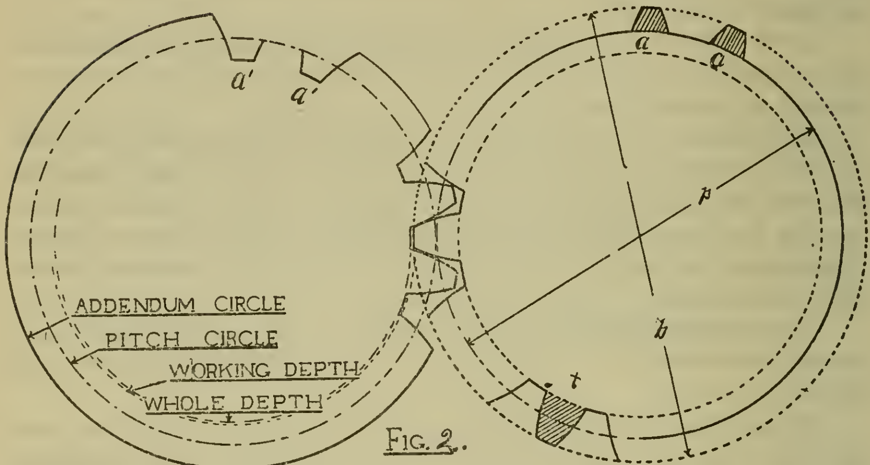


FIG. 2.

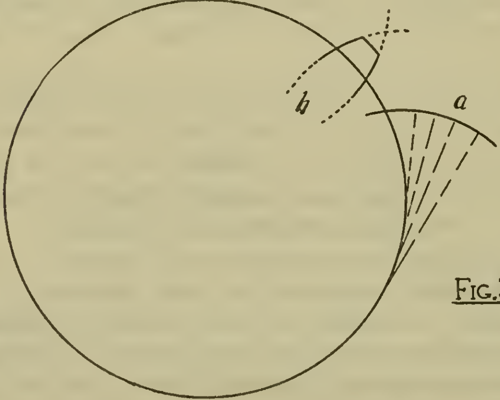


FIG. 3.

These teeth are named according to their size, as 10, 12 or 20 pitch. This is determined by the number of teeth which will just fill the circumference of a circle of unit, or 1″ pitch diameter; for example, if ten teeth of equal size will just fill the circumference of a 1″ circle, they are called 10 pitch. Teeth of half that size will require twenty to occupy the same space and are called 20 pitch.

Gears having teeth of the same pitch will run together irrespective of the number of teeth on each gear, and their velocities will vary as the ratio of their pitch diameters. For example, if the pitch distance in Fig. 1 be $4\frac{1}{2}$″, and the velocity ratio be 2 : 1, the teeth being 10 pitch, then gear A will have a pitch diameter of 3″, a blank diameter of 3.2″, and 30 teeth. Gear B will have a pitch diameter of 6″, a blank diameter of 6.2″, and 60 teeth.

The length of a tooth proportional to its pitch, is called the working depth, but in practice the tooth must be cut deeper than this in order to permit freedom of motion. This additional depth is the *clearance*.

The usual calculations for spur gears may be made with the following formulas, where

P = the pitch.
P D = pitch diameter.
C P = cir cular pitch.
C = clearance.
p d = pitch distance.
T = depth to be cut.
N = number of teeth.
B D = the blank diameter.
H = heighth of a tooth.
W = working depth.
V R = velocity ratio.

The gears in Fig. 1 being used as an illustration.

$$P = \frac{N}{PD} \quad \text{or} \quad \frac{60}{6} = 10\ P.$$

$$N = P \times PD \quad \text{or} \quad 10 \times 6 = 60 \text{ teeth.}$$

$$PD = \frac{N}{P} \quad \text{or} \quad \frac{60}{10} = 6 \text{ inches.}$$

$$H = \frac{2}{P} \quad \text{or} \quad \frac{2}{10} = 0.2 \text{ inches.}$$

$$BD = PD + H \text{ or } 6'' + 0.2'' = 6.2 \text{ inches.}$$

$$\text{Also } BD = \frac{N + 2}{P} \quad \text{or} \quad \frac{60 + 2}{10} = 6.2 \text{ inches.}$$

$$CP = \frac{3.1416}{P} \quad \text{or} \quad \frac{3.1416}{10} = 0.3142 \text{ inches.}$$

$$C = \frac{0.157}{P} \quad \text{or} \quad \frac{0.157}{10} = 0.1057 \text{ inches.}$$

$$W = \frac{2}{P} \quad \text{or} \quad \frac{2}{10} = 0.02 \text{ inches.}$$

$$T = W + C \quad \text{or} \quad 0.2 + 0.0157 = 0.2157 \text{ inches.}$$

$$pd = \frac{\text{P D of one gear} + \text{P D of the other}}{2} \quad \text{or} \quad \frac{3 + 6}{2} = 4\tfrac{1}{2} \text{ inches.}$$

V R (Velocity Ratio of two gears) equals the ratio of P D of one gear : P D of the other = (in this case) 6 : 3 or 2 : 1.

Teeth vary in length and shape according to the purpose for which they are to be used. Those in common use, and to which the preceding rules particularly apply are known as involute teeth on account of the form of the curve of the sides. They may be formed in the following manner.

Imagine a disc represented by the circle in Fig. 3 having wound around it a string tied to a pencil. The disc being of the diameter of the required pitch circle is laid on a piece of paper with the pencil point resting on a point where the edge of the tooth cuts the pitch circle. If the string be unwound the pencil will describe the line *a*; if this is done from two directions, the lines at *b*, when stopped at the right height will form the outline of the tooth.

If this be done with circles of different diameters it will be seen that the lines made when using a small circle are curved more than when a large circle, or a straight line representing a rack is employed. Therefore while the circular pitch must be the same for two mating gears, yet the shape of the side of the teeth may be different. For this reason cutters for commercial use are made in sets of eight for each pitch, each one producing a curve suitable for certain numbers of teeth.

Reference to the following table will show that a No. 2 cutter should be used for the 60 tooth gear, and a No. 4 cutter for the one having 30 teeth in order to make teeth of the correct shape.

Cutter	No.	1	cuts	from	135	to	a rack.	
"	"	2	"	"	55	"	134	teeth.
"	"	3	"	"	35	"	54	"
"	"	4	"	"	26	"	34	"
"	"	5	"	"	21	"	25	"
"	"	6	"	"	17	"	20	"
"	"	7	"	"	14	"	16	"
"	"	8	"	"	12	"	13	"

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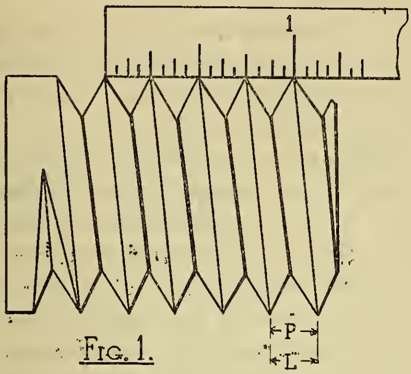


FIG. 1.

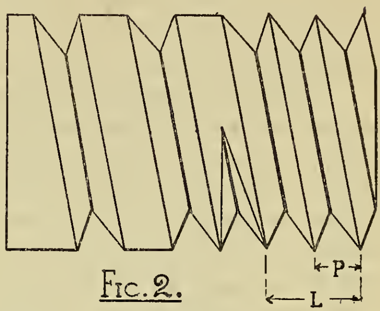


FIG. 2.

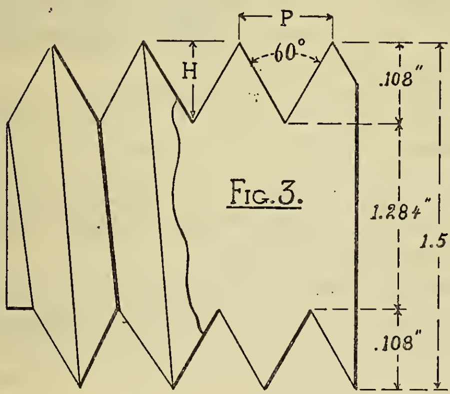


FIG. 3.

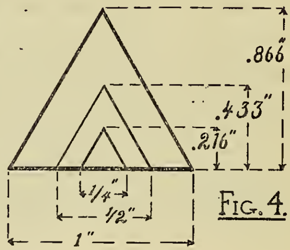
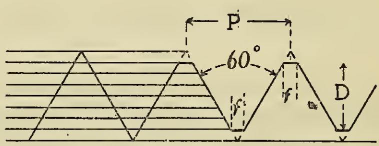


FIG. 4.

FIG. 5.



THREAD CALCULATIONS.

The threads commonly used in this country for machine work are known according to their shape as the Vee thread, the United States Standard thread, the Square thread, and the Acme thread.

They are known as right or left hand threads, according to whether they screw into a nut, or a tapped hole, with a clockwise motion or the reverse.

As machine screw threads consist of one or more grooves cut spirally around the central axis of, and in the external or the internal cylindrical surface of a body, it then follows, that a complete revolution of the body upon which the thread is cut will cause it to advance or recede a distance whose length is dependent on the angle of the thread. The distance which a thread or screw advances with each revolution is called the *lead.* The distance from the centre of one thread to the centre of the next thread is called the *pitch.*

On a single thread screw, Fig. 1, the lead and the pitch are alike; but on a double thread screw, Fig. 2, the lead is twice the pitch distance. The method of determining the pitch is illustrated in Fig. 1, where the measurement is made from centre to centre of the threads.

The Vee thread, Fig. 3, is cut with an included angle of 60° and the section of a unit thread (one per inch) of this kind would be a triangle, Fig. 4, whose base is one inch long. It may be geometrically demonstrated that such a triangle with a 1″ base is 0.866″ high, therefore, we accept this as a *constant* and as the single height of a unit Vee thread. Referring to the same figure it will be seen that a thread of two to the inch, or one of four to the inch, would be represented by triangles respectively $\frac{1}{2}''$, or $\frac{1}{4}''$ wide at the base, and that their heights would be one half, or one fourth as great as that of the unit thread. Therefore, in cutting a Vee thread the tool must cut to a depth equal to 0.866″ ÷ the number of threads to be cut per inch.

Example. Find the required depth of an 8 pitch Vee thread.

$$\text{Depth of thread} = 0.866'' \div 8 = 0.108''.$$

If it is necessary to tap a hole to receive a thread, the diameter of the hole will be equal to the outside diameter of the threaded part less the double height of the thread to be cut, Fig. 3.

Example. Required the diameter of the hole for a $1\frac{1}{2}''$ screw, 8 threads per inch, it being understood that the double height of a unit Vee thread is 2 x 0.866″ or 1.732″.

$$\text{Diameter of hole} = 1.5'' - \frac{1.732''}{8} = 1.284''.$$

The United States Standard thread (U.S.S.) has the same form as the Vee thread but the sharp points are missing, one eighth of the height being cut off at the top and one eighth at the botton, Fig. 5. In this case the single height D, of a unit thread is 0.649″ and the double height is 1.299″; the depth of thread and diameter of hole required for any thread are found in a manner similar to that employed in the case of the Vee thread.

Example. Required the diameter of hole for a 1″ bolt threaded 8 per inch U. S. S.

$$\text{Diameter of hole} = 1'' - \frac{1.299}{8} = 0.838''.$$

The American Society of Mechanical Engineers have recently adopted the following standards for U. S. S. threads, Fig. 5, Formula

$$P = \text{pitch} = \frac{1}{\text{No. threads per inch.}}$$

$$D = \text{depth} = P \times 0.64952$$

$$f = \text{width of flat} = \frac{P}{8}$$

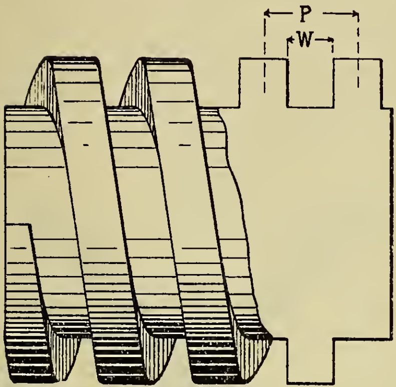


Fig. 6.

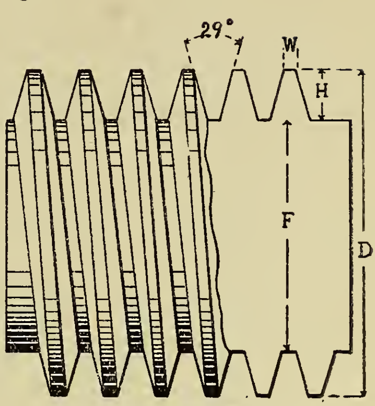


Fig. 7.

In the case of the square thread, Fig. 6, the groove, and the land (the projecting portion of the thread) are theoretically square in section, and of equal width. If a thread of four per inch be assumed, the pitch will be $\frac{1}{4}''$, and W, the width of the groove, will be 0.125″. Theoretically the working depth of the thread will also be 0.125″ but as this would cause the top of one thread to rub on the bottom of the other and thus produce unnecessary friction, the thread is given clearance by cutting it deeper by an amount equal to 0.05 of the working depth.

Example. Find the depth of a square thread 4 per inch, including clearance.

With 4 threads per inch the pitch is 0.250″, width of the groove is 0.125″, and depth equals 0.125″ x 1.05 = 0.131″.

The Acme thread, Fig. 7, is frequently used where a compromise between the square and the Vee thread is required. Its sides are inclined to form an included angle of 29° and the various dimensions may be determined by using the following formula, where

D = diameter of the screw or tap,
T = number of threads per inch
H = depth of thread,
W = width of tool point for screw thread,
E = diameter at root of thread,
C = diameter of tap,

$$H = \frac{1}{2\,T} + 0.01 \qquad E = D - \left\{\frac{1}{T} + 0.02\right\}$$

$$A = \frac{0.3707}{T} - 0.0052 \qquad C = D + 0.02$$

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METAL WORK

BEVEL GEARS.

Bevel gears connect shafts whose axes would meet if sufficiently prolonged.

If we assume two shafts at right angles as in Fig. 1, with cones on their ends as shown, we shall have the same conditions as in the case of the pitch circles in the spur gears, and the surfaces in contact are called the cone pitch surfaces.

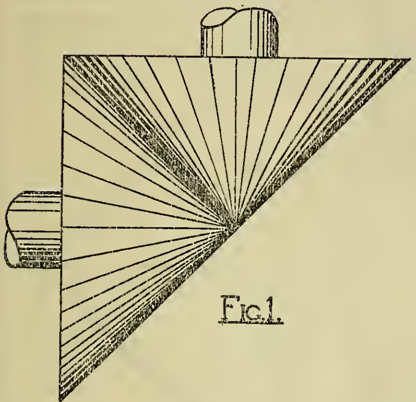

Fig. 1.

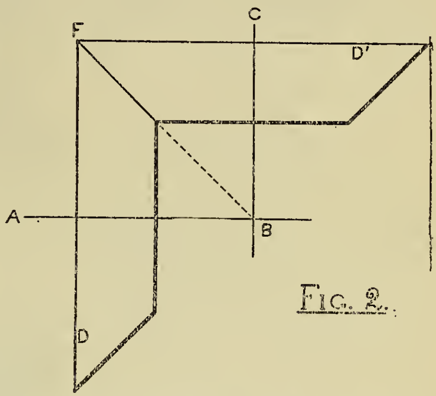

Fig. 2.

If teeth are formed on these cones, as in the case of the spur gears, we shall have bevel gears. If the teeth are made full size at the base of the cones they will become smaller as they approach the point of the cone until they finally disappear altogether; for this reason only that part of the cone which will contain teeth of effective size is used, see Fig. 2.

Simple arithmetic suffices for spur gear calculations, while geometry is required for the bevel gear; however conditions frequently require such a gear to be quickly designed in the shop, which may readily be done in the following manner:

The first step is to decide the relative shaft speed and the pitch and number of teeth to be used. When this has been done, draw the centre line of the shafts A B, and C B, as in Fig. 2, where we assume two shafts at right angles which are to run at the same speed. Then draw the pitch lines D, D′; these represent the pitch diameters of the gears, their lengths being found in the same manner as for spur gears. From the meeting point of the lines D, D′ draw a line which, if prolonged, would pass through B. The angle A B F or C B F thus formed is the pitch angle, and in the case shown, it is the same for both gears, therefore one drawing will suffice. If the pitch diameters are not alike, the angle will not be the same for both gears and a drawing must be made for each one.

Having decided to lay out the gear according to the sketch shown in Fig. 2, we find the cone pitch angle in this case, which is later called the centre angle, to be 45°, and having decided to use 45 teeth of 12 pitch, then by the same rule as for finding the pitch diameter in the case of the spur gear, we find the pitch diameter of this gear to be 3.75″.

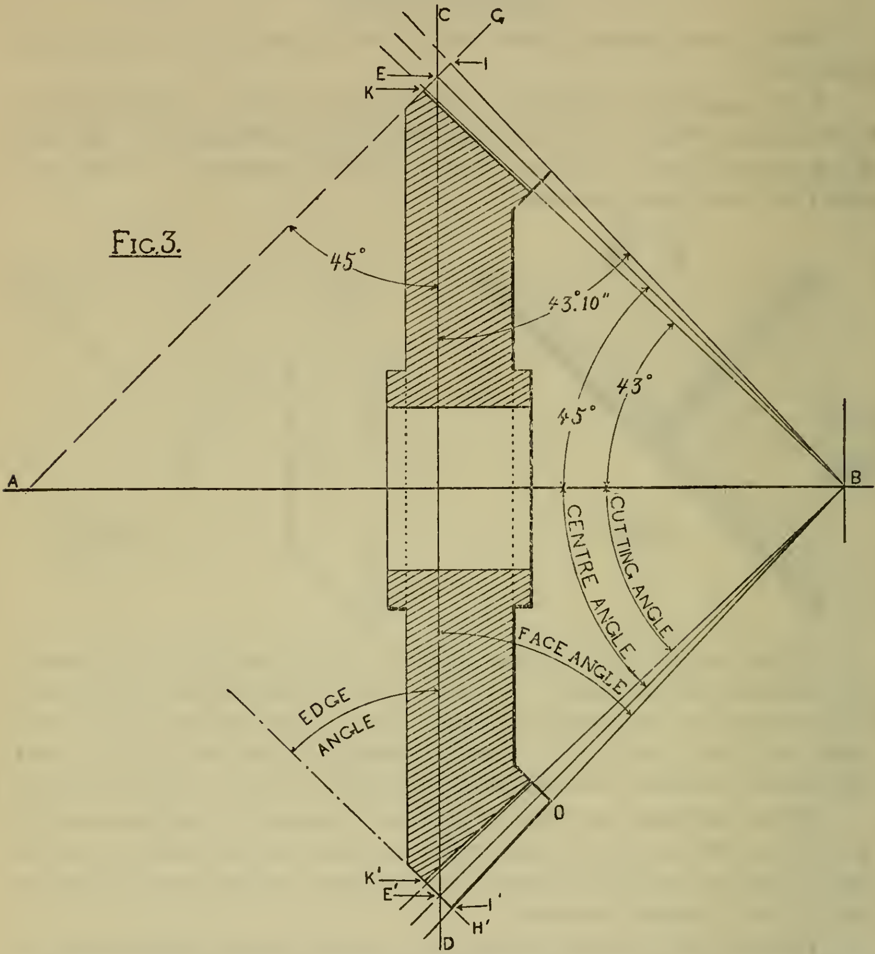

FIG. 3.

Referring to Fig. 3, draw the shaft centre line A B, and at right angles to it the pitch line C D. On C D lay off the points E, E′ equi-distant from E B, and 3.75″ apart.

Through E and E′, draw lines at an angle of 45° from A B, and meeting at the point B; these form the centre angle as shown. Through E and E′ draw the lines G and H′, at right angles to the centre angle line, and which form the back, or edge angle.

With the rule given in the leaflet on spur gears, the height of a 12 pitch tooth is found to be 0.166″. With E and E′ as centres, mark this distance on the lines G and H′, and find the points K, I, and K′, I′, representing the working depth of the tooth. Next draw the lines connecting the points K, I, K′ and I′ with B. These lines form the face or outer angle of the gear, and the cutting or bottom angle of the teeth. With the protractor these are found to be respectively as shown in the illustration. The distance between the points I and I′, called the blank diameter, is found to be 3.875″.

The length of the teeth or the face of the gear, is equal to the line I′ O, this is usually four and one half times the thickness of the teeth at the pitch circle, except when this is more than one third of I′ B. In the gear we are drawing it is 0.59″. The body of the gear may now be drawn and the gear is complete.

To find the cutter required, measure the line E A; twice this length multiplied by the pitch used equals the number of teeth for which to select the cutter. The small space below the line K B, represents the the clearance allowed in cutting.

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METAL WORK 1918.

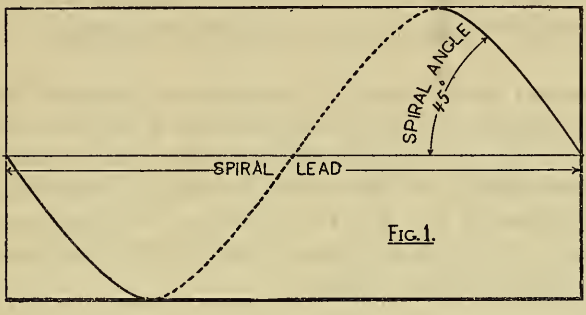

FIG. 1.

FIG. 2.

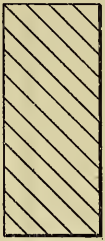

FIG. 3.

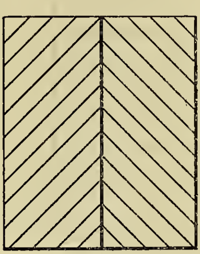

FIG. 4.

SPIRAL GEARS.

The spiral gear reduces noise, eliminates vibration, and makes it possible to transmit power through gears at extremely high speeds.

The angle of the teeth is always understood to be taken from the axis of the gear Fig. 1.

The *spiral lead* is the distance travelled by a tooth in one complete revolution of the gear, and may be found by multiplying the pitch circumference by the cotangent of the spiral angle. The lead is zero when the spiral angle is at 90° to the axis of the gear, and increases as the spiral angle decreases until at 45° it is equal to the pitch circumference; when the angle finally becomes zero the lead is infinite and a spur gear is the result.

The spirals may be either right or left hand, as required. Fig. 2 is a left hand and Fig. 3, is a right hand gear. When both are of the same hand the angle of the shafts equals the sum of the spiral angles.

When they are of opposite hands the angle of the shafts equals the difference of the spiral angles.

The end thrust produced by single gears may be avoided by the use of herring bone gears, Fig. 4.

The velocity ratio of two gears may be changed by altering the number of teeth, or their angle.

When the angle of one gear is the same as that of the shafts, the other will be a spur gear.

With shafts at right angles, the angles of the spirals must be of the same hand.

With parallel shafts one gear must be right, and the other left hand. With an acute shaft angle the gears may be either alike or opposite hand spirals.

The normal circular pitch is the distance between the centres of two teeth measured on the pitch circle and at right angles to the length of the teeth. In the spur gear this is equal to the distance between the tooth centres at their ends, and may be measured directly on the side of the gear G, Fig. 5. The direction in which measurements on the normal pitch circle are taken is indicated by the broken line P, in the three instances shown in Fig. 5.

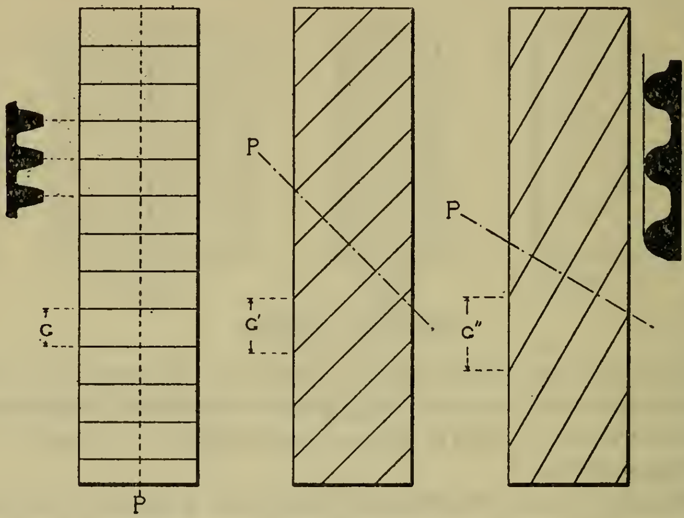

FIG. 5.

If teeth of the same pitch are to be cut with a spiral angle of 45°, Fig, 5 the normal pitch must be the same as before but the circular pitch measured on the side of the gear will be longer than before, G′ and if the teeth are cut with a spiral angle of 60′ the circular pitch G″ on the side of the gear Fig. 5, will be still longer than in either of the previous instances.

Therefore it is evident that if three gears are cut each having the same number of teeth and all of the same pitch, but with different spiral angles, the pitch diameters will vary according to the spiral angles.

Assuming that it is required to cut a gear having 80 teeth, of 10 pitch, and a spiral angle of 30° the following method may be employed to determine the remaining factors.

$$\text{Normal circular pitch} = \frac{3.1416''}{\text{pitch}} \text{ or } \frac{3.1416''}{10} = 0.3142''$$

$$\text{Cir. pitch} = \frac{\text{Nor. cir. pitch}}{\text{cosine of} <} \text{ or } \frac{0.3142''}{0.86603} = 0.3627''$$

Pitch cir. = Cir. pitch x No. of teeth, or 0.3627″ x 80 = 29.015″

$$\text{Pitch dia.} = \frac{\text{P. cir.}}{3.1416} \text{ or } \frac{29.015''}{3.1416} = 9.235''$$

$$\text{Blank dia.} = \text{P D} + \frac{2}{\text{P}} = 9.235'' + 0.2'' = 9.435''$$

$$\text{No. of cutter} = \frac{\text{No. of teeth}}{(\text{cos. of angle})^2} = \frac{80}{0.75} = 106 = \text{No. 2 cutter}$$

$$\text{Spiral lead} = \frac{\text{P. cir.}}{\text{tangent of} <} \text{ or } \frac{29.015''}{0.57735} = 50.25''$$

SHOPWORK LEAFLETS

METAL WORK

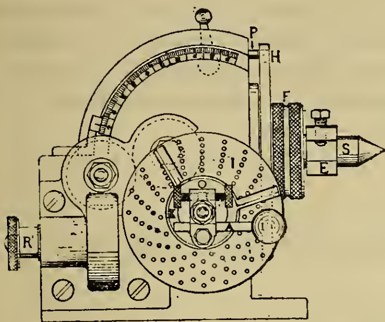

FIG. 1.

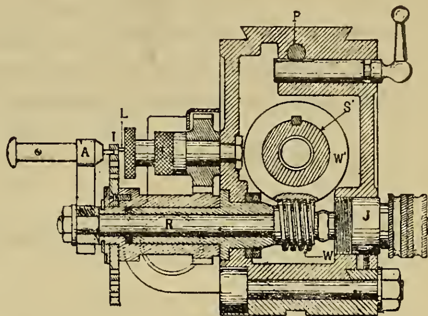

FIG. 2.

THE MILLING MACHINE DIVIDING HEAD

A common use of the milling machine is for the accurate division of circles. These divisions may be in the form of graduations, flat surfaces, straight teeth as on spur gears, reamers and cutters, or spiral cuts as in spiral gears, drills and milling cutters.

The dividing, or index head, used for this purpose, Fig. 1, is essentially simple; those used on the various milling machines are similar in construction and involve, as the basic principle of operation, the use of a worm and worm wheel, Fig. 2. The spindle of the latter, S′, carries the work to be divided, either between centres, one of which is shown at S Fig. 1, equipped with a face plate E; or by means of a chuck or an arbor. The chuck is held on the spindle by a thread which is protected when not in use by the knurled ring F.

For making straight teeth or divisions, three methods are employed, known as simple, plain and differential indexing. In simple indexing the worm is disconnected from the wheel by shifting the eccentric bearings, one of which is shown at J Fig. 2, and the spindle may then be revolved directly by hand. The front of the spindle carries a plate H pierced near its edge with 24 holes, and the head is provided with a stop pin P which may be inserted in these holes in order to hold the spindle in any desired position. By this means a circle may be divided into 2, 3, 4, 6, 8, 12 or 24 parts.

Other divisions may be made by plain indexing, which requires that the worm and wheel be connected, while pin P Fig. 1 is withdrawn and the spindle turned by means of the index arm and pin A, which is fastened to the worm shaft R, the index plate I being held stationary by the locking pin L. With a single thread worm, and on the spindle a worm wheel of 40 teeth, it is evident that one revolution of the worm will turn the spindle $\frac{1}{40}$ of a revolution, and that 40 turns of the worm will cause one complete revolution of both the spindle and the work.

For example, it will be necessary to turn the worm once for every tooth, if a gear of 40 teeth is being cut; one half-turn for 80 teeth; and two turns for each tooth if 20 teeth are being cut. If this ratio of 40 to 1, existing between the worm and wheel, be borne in mind, it is evident that the amount necessary to move the worm, in order to move the spindle and work sufficiently to produce any required division of a circle, may be expressed by a common fraction wherein the numerator is the ratio 40, and the denominator is the number of divisions required.

For example, 40 divisions $= \frac{40}{40} = 1$ turn; $80 = \frac{40}{80} = \frac{1}{2}$ turn, and

$20 = \frac{40}{20} = 2$ turns of the worm for each division on the work.

Also 30 divisions $= \frac{40}{30} = 1\frac{1}{3}$ turns, and $45 = \frac{40}{45} = \frac{8}{9}$ of a turn.

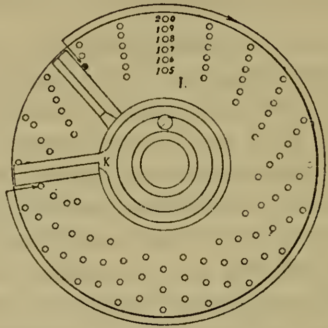

FIG. 3.

For convenience, the head is equipped with index plates I, Fig. 3, upon which are concentric circles, each circle being marked to indicate the number of holes which it contains. These holes are for the purpose of receiving the index pin and thus locking the index arm by which the worm is turned while the cut is being taken. In order to minimize the number of circles and plates required, it is usual to drill such a number of holes as will permit one circle to serve for obtaining several divisions. For example, a circle with 24 holes will serve for divisions requiring one turn by inserting the pin in the same hole after each turn; for $1\frac{1}{2}$ turns move the pin once around and 12 additional holes; for 30 divisions make one turn and 8 additional holes. A circle with 18 holes would serve the same purpose, as 18 is divisible by 1, 2, and 3; it would also serve for making 45 divisions which requires $\frac{8}{9}$ of a turn for each division, and the pin would in this case be moved $\frac{8}{9}$ of 18 or 16 holes. To facilitate moving the pin the correct distance, the head is provided with a sector K which may be so adjusted that the space between its arms includes the holes to be moved and makes it unnecessary to count the holes each time the pin is moved. For example, in cutting a gear with 48 teeth the worm must be moved $\frac{5}{6}$ of a turn for each tooth, and

Use an index circle with a number having factors that are contained in the change gears on hand; these are: 24 (2), 28, 32, 40, 44, 48, 56, 64, 72, 86, 100. If H contains a factor not found in these gears X cannot usually be obtained unless the factor is cancelled by the difference between HV and DN, or unless D contains the factor.

When HV is greater than DN and gearing is simple, use 1 idler.

When HV is less than DN and gearing is simple, use 2 idlers.

When HV is greater than DN and gearing compound, use no idlers.

When HV is less than DN and gearing compound, use 1 idler.

Select N so that the ratio of gearing is not more than 6:1, to avoid excessive strain on gears.

Example: Find gears for cutting 59 teeth.

D = 59. Assume H = 33, N = 22

$$\text{Then } X = \frac{(33 \times 40) - (59 \times 22)}{33} = \frac{22}{33} = \frac{2}{3}$$

Select gears of the ratio, 32 to 48, place the 32 on the spindle and the 48 on the worm; HV being greater than DN and the gearing being simple, use 1 idler.

Example: Find gears for cutting 321 teeth.

D = 321. Assume H = 16, N = 2.

$$\text{Then } X = \frac{(321 \times 2) - (16 \times 40)}{16} = \frac{1}{8}$$

As this ratio is not obtainable by simple gearing with the gears on hand, we express it in compound gearing as follows:

$\frac{3 \times 1}{8 \times 3}$ or gears $\frac{24 \times 24}{64 \times 72}$ and place them as follows: on worm 72, 1st. stud 24, 2nd. stud 64, spindle 24. As HV is less than DN, and gearing compound, use 1 idler.

In setting the head for graduating degrees, the adjustment must be for 360 divisions and can be done by plain indexing; for quarter degrees there will be 1440 divisions for a complete circle and the gearing will be worked out as above. If it is desired to graduate a Vernier reading to $\frac{1}{12}$ of a degree, or 5 minutes, each Vernier space will equal $\frac{11}{12}$ of a degree and we will have

$\frac{11}{12} \times \frac{1}{360} = \frac{11}{4320}$ or $\frac{4320}{11}$ spaces in the whole circle = 392 $\frac{8}{11}$ spaces.

Assuming H = 18, N = 2.

$$\text{Then } \frac{(392\frac{8}{11} \times 2) - (18 \times 40)}{18} = \frac{\frac{720}{11}}{18} = \frac{720}{11} \times \frac{1}{18} = \frac{40}{11} = \frac{64 \times 100}{40 \times 44}$$

for the gears, and one idler will be used.

When cutting spirals only plain indexing may be used as it is necessary to release the locking pin in the back of the index plate and connect the worm and the lead screw of the table by a train of gears in order that the work may be revolved on its center, and advanced against the cutter at the same time; the principles involved being similar to those employed when cutting threads on the lathe, except that compound gearing is almost invariably necessary. While the following figures were calculated with reference to the Brown & Sharpe milling machine they are applicable to any miller having a lead screw of 4 threads per inch and a ratio of 40 to 1 in the index head. In such a case if the lead screw and worm be connected by gears of equal size, the work will make $\frac{1}{10}$ or $\frac{4}{40}$ of a revolution for each inch the table advances, and one complete revolution for each 40 turns of the lead screw, each turn advancing the table $\frac{1}{4}''$ or a total of 10″ for the entire 40 turns.

If it is desired that the work make one turn while advancing 24″, a convenient method of obtaining the gear ratio is as follows: 24 x 4 = 96, or the number of revolutions of the screw during one turn of the work.

The ratio and position of the gears would then be $\frac{96 = \text{driven gear.}}{40 = \text{driving gear.}}$

As this cannot be operated as a simple train, it may be compounded as follows: resolve $\frac{96}{40}$ into $\frac{8 \times 12}{5 \times 8}$ then multiplying each fraction by a convenient number we have $\frac{(8x8) \times (12x6)}{(5x8) \times (8x6)} = \frac{64 \times 72}{40 \times 48}$ $\begin{matrix} = \text{driven gears,} \\ = \text{driving gears.} \end{matrix}$

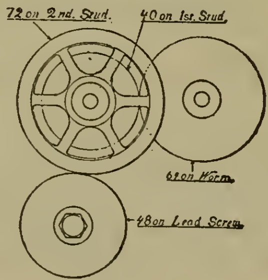

Fig. 5.

Place them, Fig. 5, in this order: first driver on screw 48, second driver, 1st. or inside gear on stud 40; first driven, 2nd. or outside gear on stud 72, second driven, gear on worm 64. Should the gears as given interfere or not mesh properly; either the drivers or the driven gears may be transposed, but a driver may not be substituted for a driven.

Should the figures call for a gear not among those on hand, the numbers may be changed providing the ratio remains unchanged, for example if a circle of 18 holes be used the sector will be set as in Fig. 3, the pin traversing the distance from the full hole next to one arm, to the hole next to the other arm, will move 15 holes, or the required part of one turn. The sector is then slipped around, again bringing the first arm in contact with the pin and is ready for the next movement.

In setting the sector care must be taken not to count the hole in which the pin is placed at the start. Remember, it is the holes *moved* which are to be counted; in fact error may be avoided by counting the spaces traversed by the pin instead of the holes.

It is also best to become accustomed to moving the pin always in the same direction in order to avoid error due to the lost motion which may exist; and for the same reason, if the pin should be moved beyond the correct hole, do not simply come back to it, but move back enough to take up the lost motion and then enter the pin in the proper hole while it is advancing in the forward direction.

Several index plates and a table giving the circle and number of holes to be used are furnished with each machine, but a knowledge of the principles involved makes it unnecessary to constantly refer to the table and will save the time required for changing plates in cases where a plate already on the machine may be used instead of the one given on the table. For example, 6 divisions being required, the table gives us circle 18; but if a plate with circle 21 is on the machine it need not be changed, as the necessary $6\frac{2}{3}$ turns may be made on this circle as well as on the 18 circle.

Occasionally work must be replaced in the machine in order to be recut, and difficulty may be found in adjusting the cutter exactly to the center of the original cut. Some machines, like the Brown & Sharpe, provide an adjustable index arm, A Fig. 1, which is convenient for such adjustments and permits the pin to be brought to the nearest hole without disturbing the setting of the work.

To adjust the arm after the work has been placed in position, lock the index plate by means of the stop pin at the back and adjust the arm by means of the knurled screws until the index pin enters the nearest hole.

To rotate the work relative to the index plate, both the stop pin at the back and the index pin should be engaged; the adjustment may then be made by means of the screws.

Certain divisions, such as 51, 53, and other prime numbers cannot be indexed in the usual manner and then compound or differential indexing methods must be used. Assuming that 57 divisions are desired, the index will be set as for 56 and the work-carrying spindle be geared to the worm so that as the worm moves forward enough for 56 divisions, the spindle is slipped back or retarded sufficient to make the distance moved by the work equal to that required for 57 divisions. In other cases it is advanced the required amount.

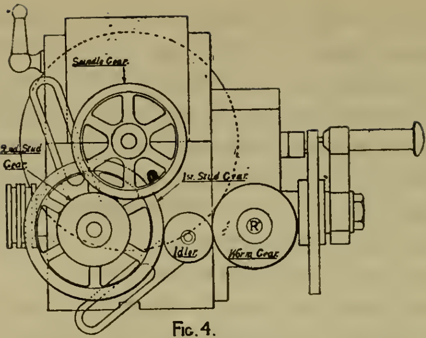

Fig. 4.

Differential indexing, as done on the Brown & Sharpe milling machine is illustrated in Fig. 4, where the center S, Fig. 1, carrying the work, has been replaced by another fitted to take one of a gear train connecting the center, or work-spindle, to the worm shaft and index plate, by means of the permanent gears on the head terminating in the shaft R′ (as this is practically an extension of the worm it will hereinafter be so called) which causes the plate to rotate either in the same or in the opposite direction to that in which the pin arm is turned, as may be required. The total movement of the arm at each indexing is, therefore, equal to its movement relative to the plate, plus the movement of the plate when the plate revolves in the same direction as the arm; or minus the movement of the plate when it revolves in the opposite direction to the arm. The formulae for finding the ratio of gears to be used are as follows, where $V = 40$:

$$X = \frac{HV - DN}{H} \text{ if HV is greater than DN.}$$

$$X = \frac{DN - HV}{H} \text{ if HV is less than DN.}$$

$$X = \frac{S}{W} \text{ for simple gearing.}$$

$$X = \frac{S\,G'}{G^2 W} \text{ for compound gearing.}$$

D = divisions required.
N = number of holes taken at each indexing.
V = ratio of gearing between spindle and pin arm.
H = holes in index circle.
X = ratio of gear train between spindle and index plate.
S = gear on spindle. } Drivers.
G^1 = 1st. gear on stud. } Drivers.
G^2 = 2nd. gear on stud. } Driven.
W = gear on worm. } Driven.

$\frac{72}{48} = \frac{3}{2}$ and $\frac{3 \times 16}{2 \times 16} = \frac{48}{32}$ While this changes the gears in the last pair, the ratio is as before and the final result is unchanged. When using the gears above mentioned, a point resting on the work will describe a right hand spiral on the surface; for a left hand spiral an idler is placed between a driver and the gear driven by it.

To prove these gears, take the continued product of the lead screw and the driven gears, and see whether it equals the continued product of the ratio between the distance the work moves, to one turn (24″ in this case), and the constant 40, together with the drivers.

$\frac{1}{4} = .25$

$\frac{24}{40} = .6$

then $\frac{.25 \times 64 \times 72 = 1152}{.6 \times 40 \times 48 = 1152}$

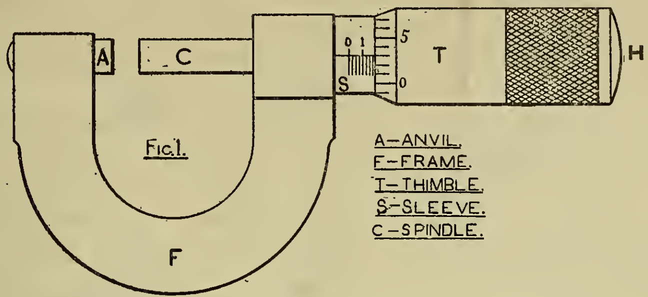

Fig. 1.

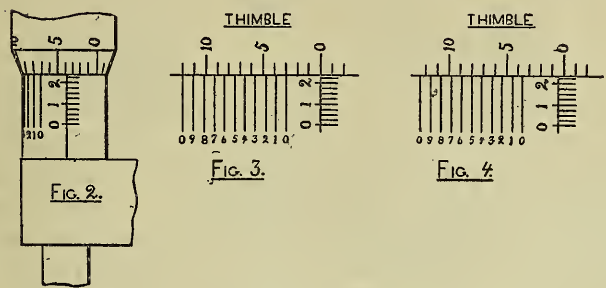

Fig. 2. Fig. 3. Fig. 4.

THE MICROMETER.

The micrometer is a precision measuring instrument which is constantly used as an aid in the production of accurate work. A common form of micrometer is illustrated in Fig. 1.

The object to be measured is placed between the anvil A, and the spindle C, the latter being adjustable by means of the thimble T. When both the anvil and spindle are in contact with the object to be measured, the size is indicated by the graduations on the thimble T and the sleeve S.

The spindle is attached to the interior of the thimble at H, and revolves with it. The part of the spindle which is concealed within the sleeve and thimble is threaded to fit a nut in the frame F. When the thimble is revolved the spindle revolves with it and moves through the nut in the frame and approaches, or recedes from the anvil.

The pitch of the screw threads on the concealed part of the spindle is 40 to an inch. One complete revolution of the spindle therefore moves it one fortieth (or twenty-five thousandths) of an inch. The sleeve S is marked with 40 lines to an inch, corresponding to the number of threads on the spindle. When the micrometer is closed, the beveled edge of the thimble coincides with the zero line on the sleeve, and the zero line on the thimble agrees with the horizontal line on the sleeve. Open the micrometer by revolving the thimble one revolution, or until the zero line on the thimble again agrees with the horizontal line on the sleeve; the distance between the anvil and the spindle will now be $\frac{1}{40}''$ (0.025″), and the beveled edge of the thimble will be on the second vertical line on the sleeve. Every fourth vertical line is made longer than the others and is numbered 1, 2, 3, etc. Thus each numbered line indicates a distance of four times $\frac{1}{40}''$ or $\frac{1}{10}''$ (0.1″).

The beveled edge of the thimble is marked in twenty-five divisions, and every fifth line from 0 to 25 is numbered. Rotating the thimble from one of these marks to the next moves the spindle longitudinally $\frac{1}{25}$ of 0.025″ or 0.001″; two divisions indicates 0.002″; and a complete revolution or twenty-five divisions indicates a movement of 0.025″.

To read the micrometer, multiply the number of vertical divisions visible on the sleeve by 25, and add the number of divisions on the bevel of the thimble from zero to the line which agrees with the horizontal line on the sleeve. For example, in Fig. 1, seven divisions are visible on the sleeve, multiplying this number by 25 and adding the three on the bevel, the sum shows the micrometer to be open $7 \times 25 + 3 = 0.178''$ or one hundred and seventy-eight thousandths of an inch.

Readings in ten thousandths of an inch are obtained by the use of the Vernier. On the micrometer this consists of ten divisions on the sleeve, which occupy the same space as nine divisions on the thimble, Figs. 2 and 3. The difference in the width of one of the ten spaces on the sleeve and one of the nine spaces on the thimble is therefore equal to one-tenth of a space on the thimble. In Fig. 3, the reading is in even thousandths and the zero on the thimble agrees with the horizontal line. The third line on the thimble agrees with the zero line on the vernier, the next two lines on the thimble and sleeve do not coincide by one tenth of a space on the thimble, the next two, marked 5 and 2, are two-tenths apart and so on. Remember that each division on the spindle indicates one-thousandth of an inch, therefore if the thimble be turned so that the lines 5 on the thimble and 2 on the sleeve coincide, the micrometer will be opened two-tenths of one-thousandth, or two ten-thousandths. If it is turned until the eighth line on the thimble coincides with the fifth line on the vernier, Fig. 4, it will have been opened five ten-thousandths and the reading will be 0.2255″.

To read in ten-thousandths, first read the thousandths as previously described and then add as many ten-thousandths as are indicated by the number of the line of the vernier which corresponds with a line on the thimble.